

PM015 – 08 February 2024

Update on PINNs

Application to Urban Wind Field Dispersion Studies

Content

- 1) La Defense – Full Dataset Training (GPU Workstation)
- 2) La Defense – Reduced Dataset Training (GPU Laptop)
- 3) La Defense – Full Dataset Training (Google Colab A100 GPU)

Script Version v5

- 1) PINN is now completely customizable – customizable input and output parameters, batch normalization, dropout rate, neuron number, number of hidden layers – all options in the config file (PM007)
- 2) Saving of all the losses (not just the total loss) (PM007)
- 3) Plotting of loss vs epochs now automatic (PM007)
- 4) Boundary conditions – relaxed no slip condition included (PM007)
- 5) New angles included (PM007)
- 6) Smaller batch sizes (I disagree) – customizable from config file (PM007)
- 7) Testing and Predicting Loss during training phase (PM008)
- 8) Inlet Boundary Conditions added (PM008)
- 9) Inlet Boundary for the Z-direction made to follow a log equation (PM009)
- 10) Debugged for no slip loss BC (PM009)
- 11) Activation function updated to an exponential linear unit instead of ReLu {arXiV: 1511.07289} (PM0010)
- 12) Script is being modified for TPU use (PyTorch → Tensorflow) (PM010)
- 13) Entire script revamped for optimisation (PM011)
- 14) Adaptive Weighting Scheme implemented (PM011)
- 15) Moving averages for stopping condition implemented (PM011)
- 16) Amount of data to be considered for data loss is configurable (PM011)
- 17) Plotting divergence implemented (PM011)
- 18) When running in batch mode, each batch now contains a fair representation of all angles in the training phase (PM011)
- 19) Script has been modified for TPU use for data loss only (PyTorch → Tensorflow) (PM011)
- 20) Divergence computations now compares numerical differentiation on the unstructured grid vs PyTorch's autograd (PM012)
- 21) **Normalization transformation fixed for Divergence computation (PM014)**
- 22) **RANS computation added (PM014)**
- 23) **Script to obtain derivatives from Paraview (PM014)**

LA DEFENSE

Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (121 Epochs, not completed), Full Dataset, GPU Workstation

Scripts v5 – TESTING

Some Parameters

Infinite epochs - Simple Moving Average stopping condition

128 Neurons for the PINN unless otherwise specified (50949 parameters in total)

We have the data for 13 angles, [0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180] in degrees

We concatenate the data for angles = [0, 15, 30, 45, 60, 75, 90, 105, 120, 150, 165, 180] and then take 99% of the dataset with random seed = 42 for training and 1% for testing

By using 99% of the whole dataset we hope to make the NN learn about wind angle such that the parameters become functions of the wind angle

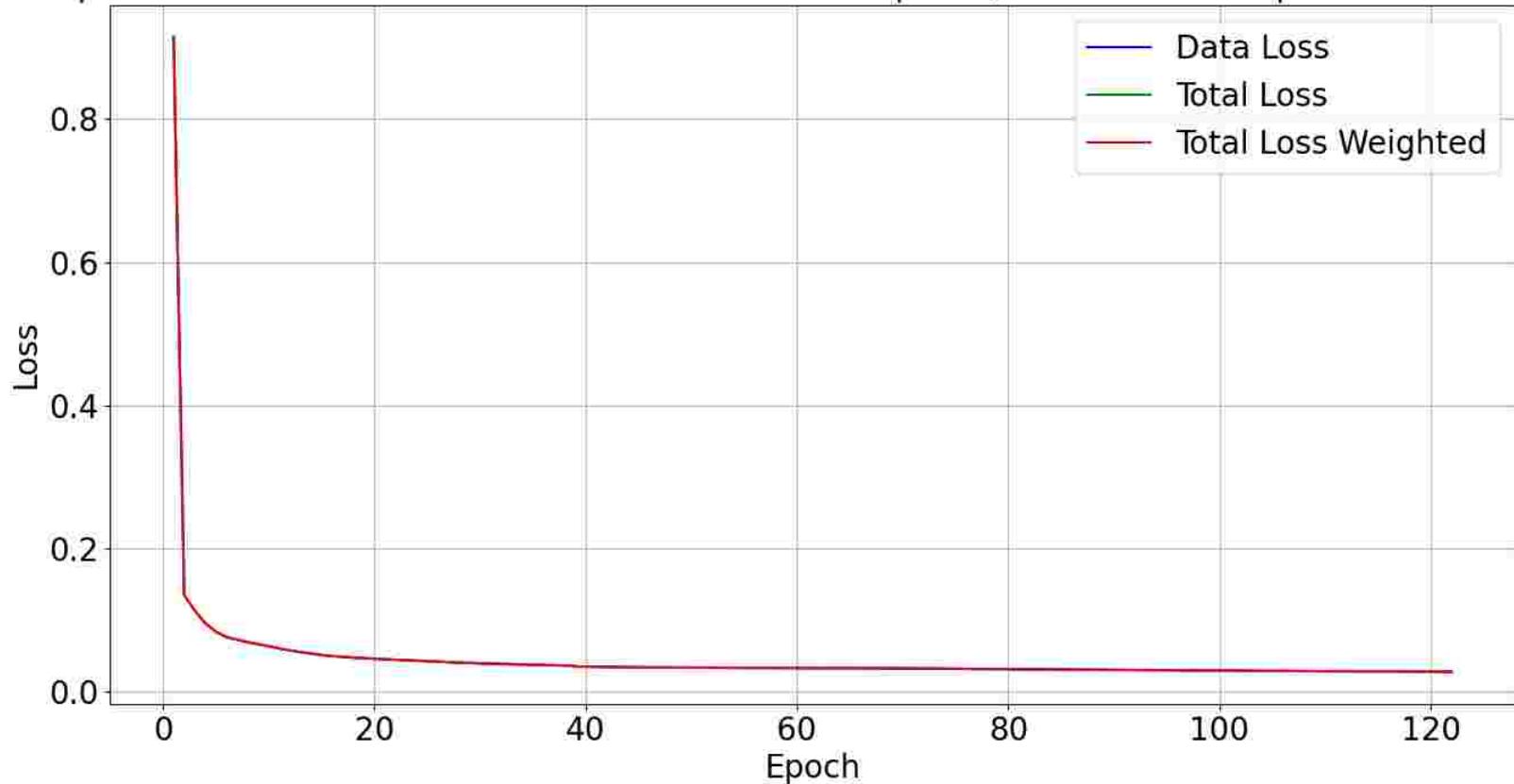
Then using the trained neural network we predict the data for angle = 135

For this run, we will only have input parameters to be [X, Y, Z, $\cos(\theta)$, $\sin(\theta)$] and the output parameters will be [U, V, W]

Total Number of Data Points → 1.21954E7 points per wind angle * (5 inputs + 3 outputs) * (12 training wind angles) ~ 1.17E9
(~1.46E9 if we include Pressure and TurbVisc)

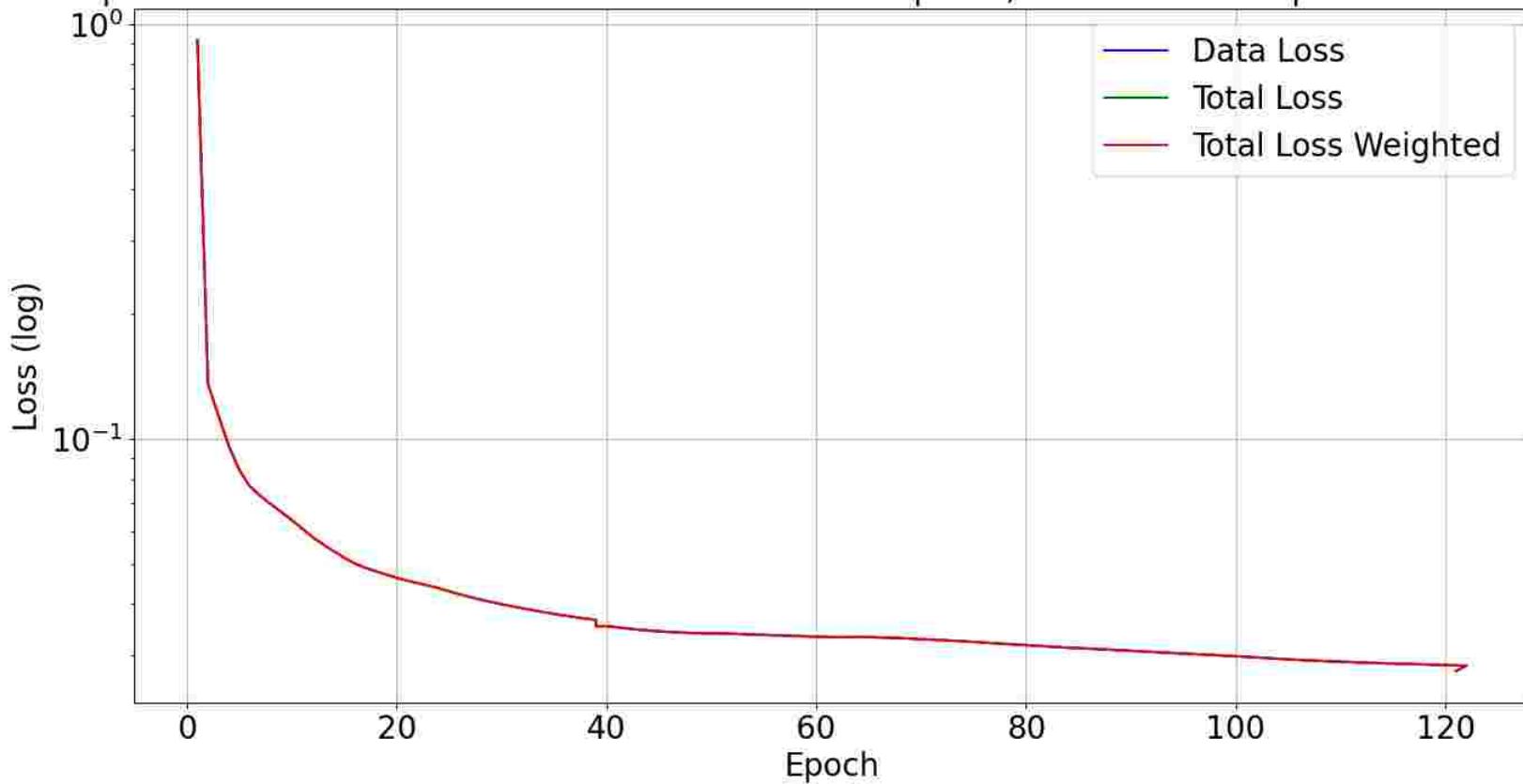
Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), GPU Workstation
Logging Plots (Training)

Epoch vs Loss - Time Taken = 498.85 hours for 121 Epochs; Time Taken Per Epoch = 4.12 hours

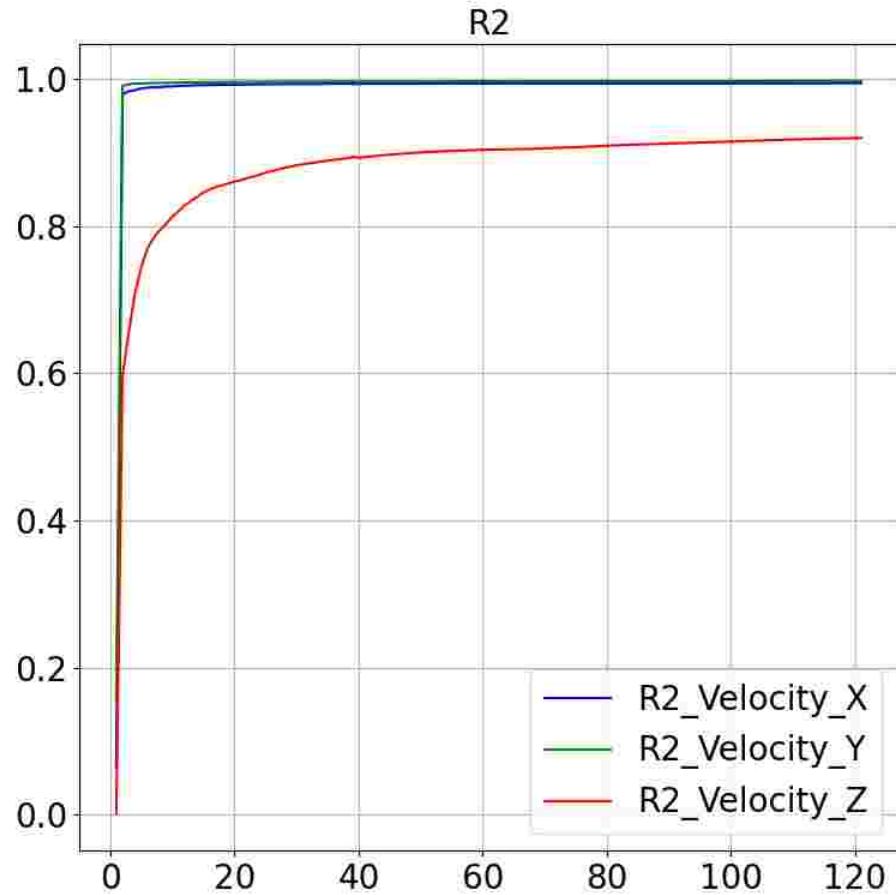
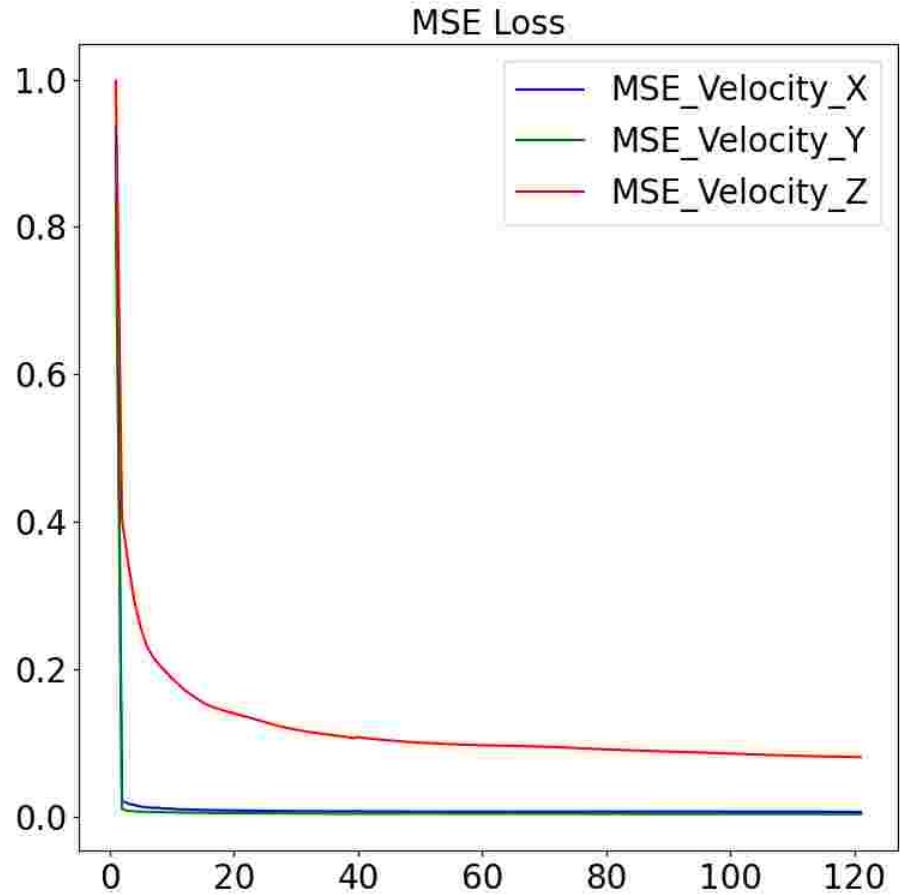


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), GPU Workstation
Logging Plots (Training)

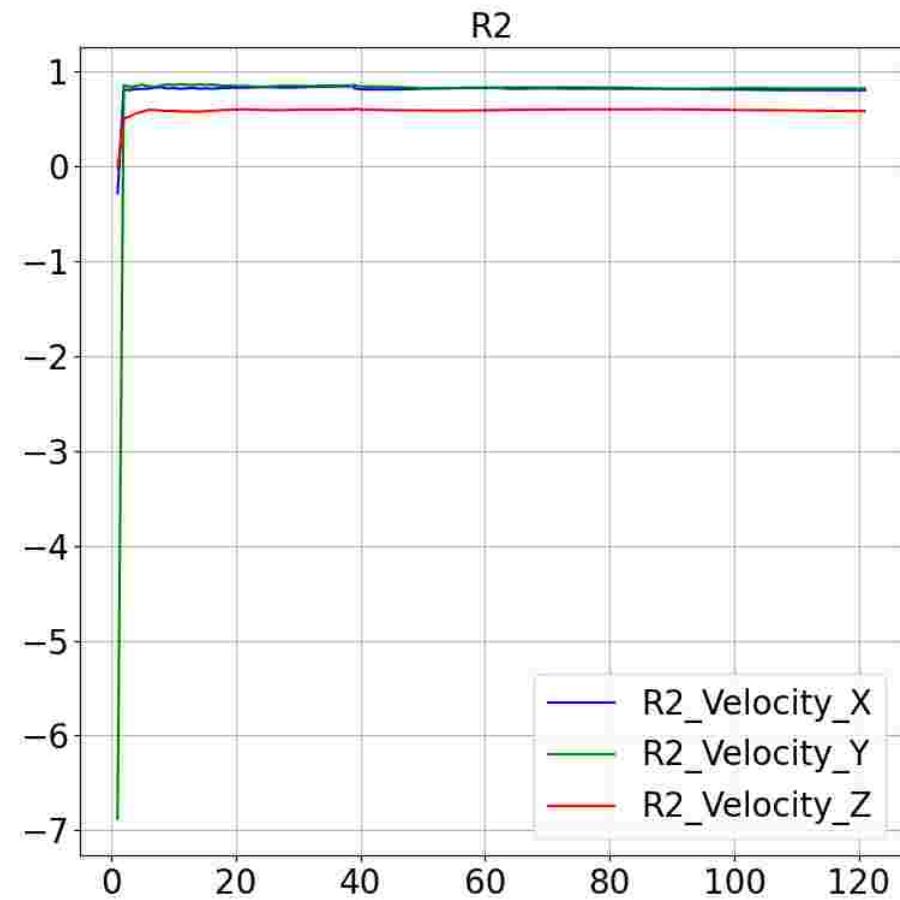
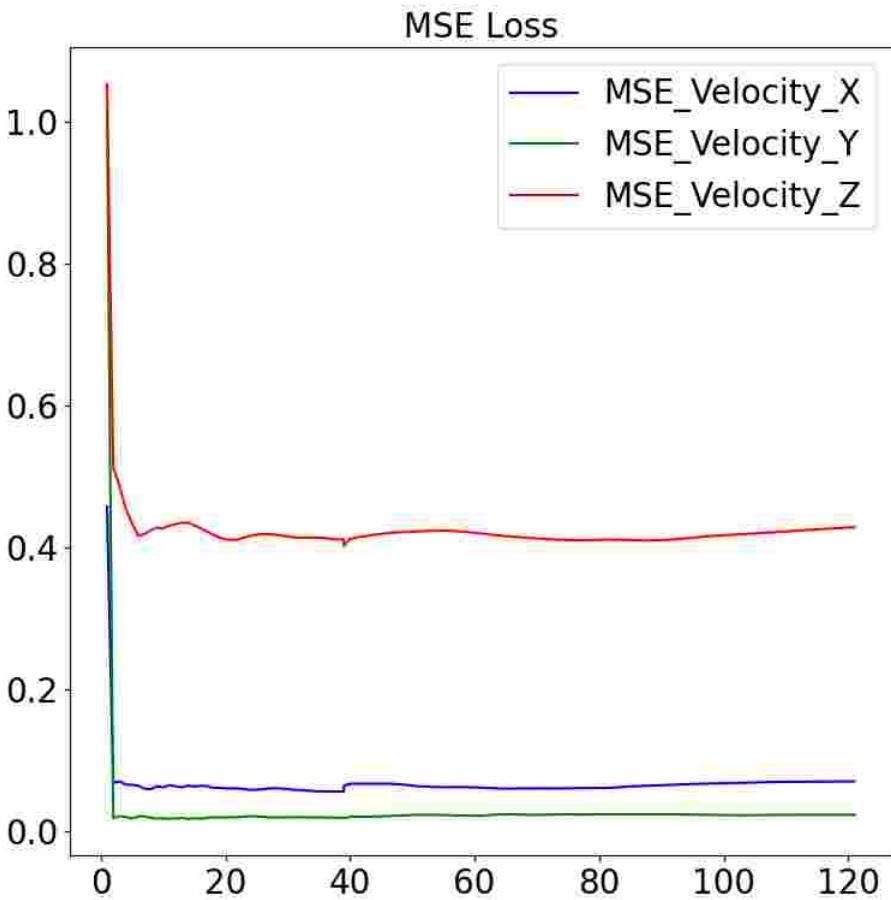
Epoch vs Loss - Time Taken = 498.85 hours for 121 Epochs; Time Taken Per Epoch = 4.12 hours



Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), GPU Workstation
Logging Plots (Testing)

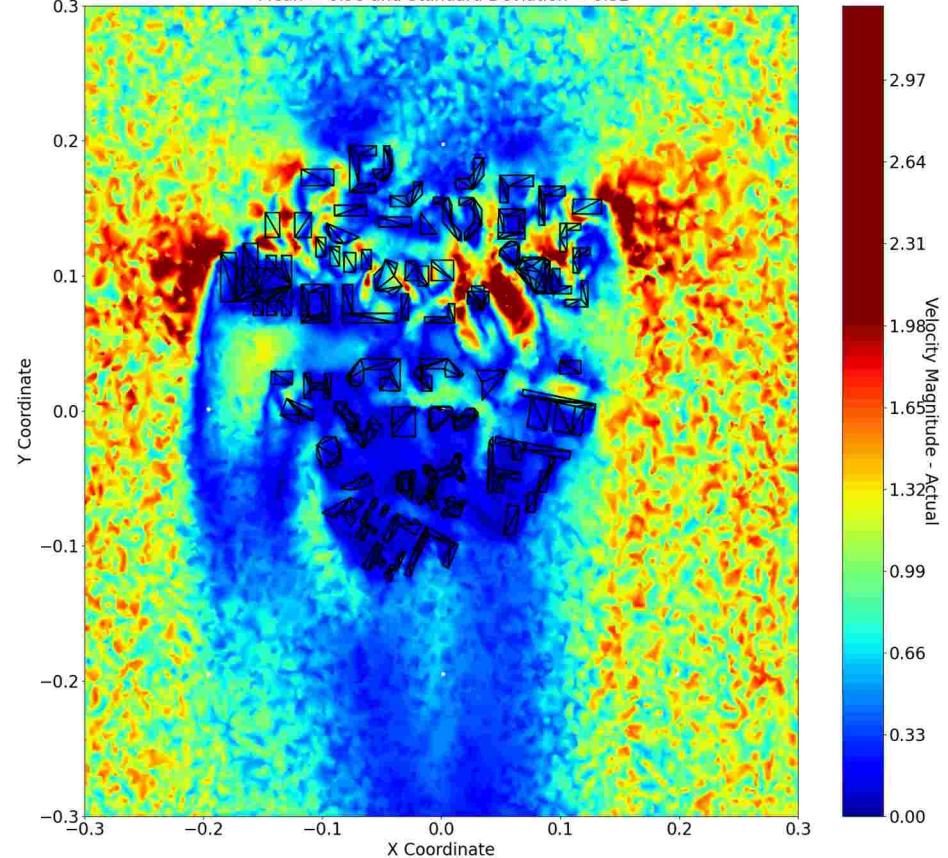


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), GPU Workstation
Logging Plots (Predicting 135)

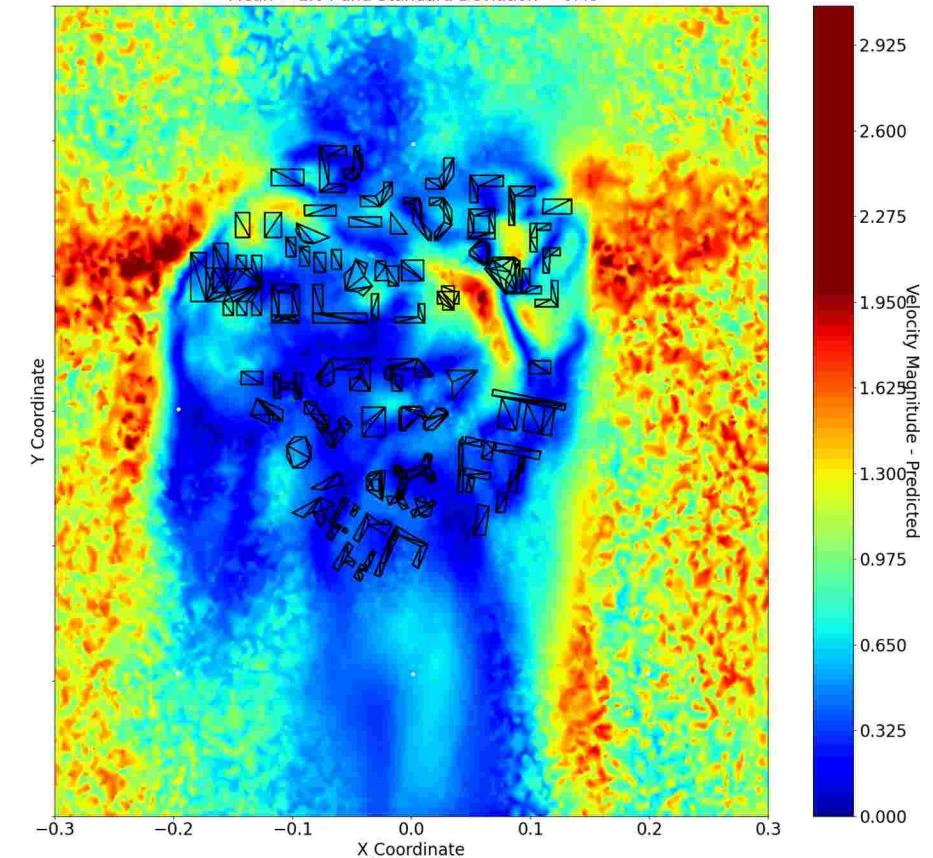


Comparison of Actual vs. Predicted values with Wind Angle = 0 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01
Mean = 0.98 and Standard Deviation = 0.52

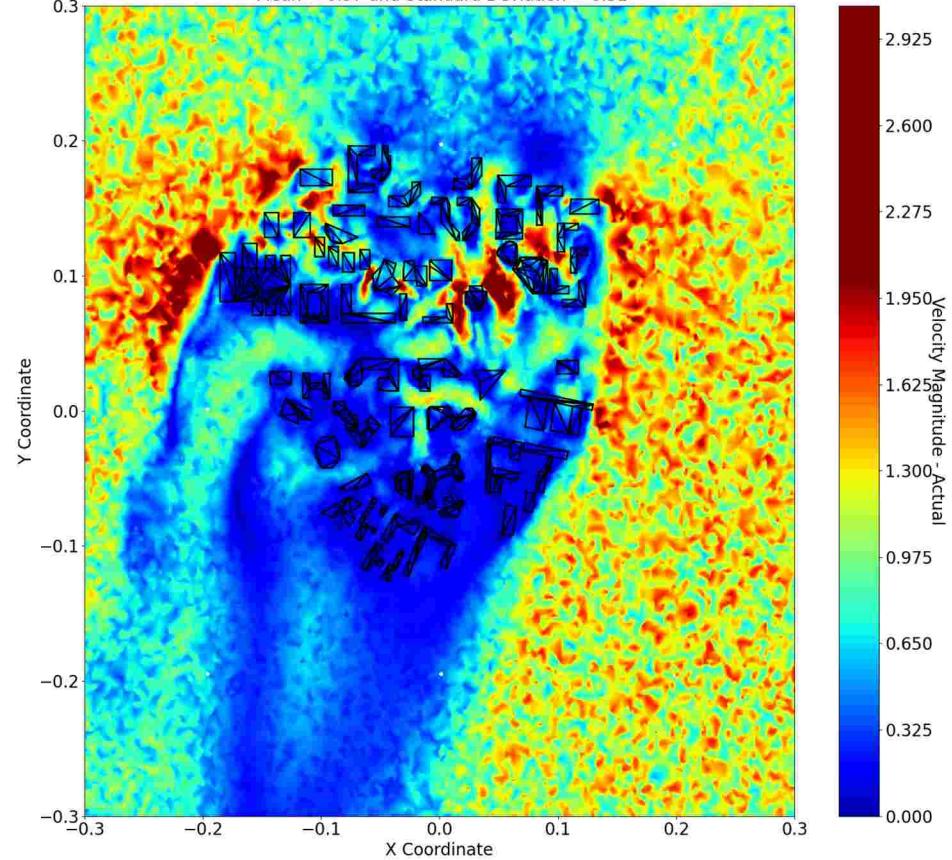


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.49

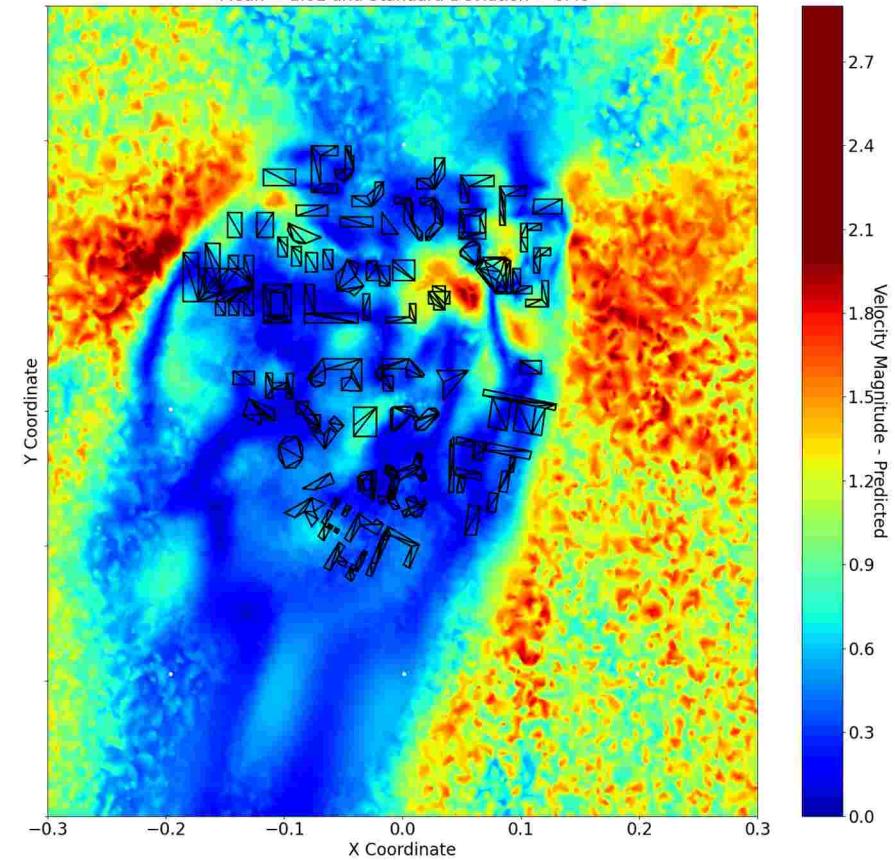


Comparison of Actual vs. Predicted values with Wind Angle = 15 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01
Mean = 0.97 and Standard Deviation = 0.52

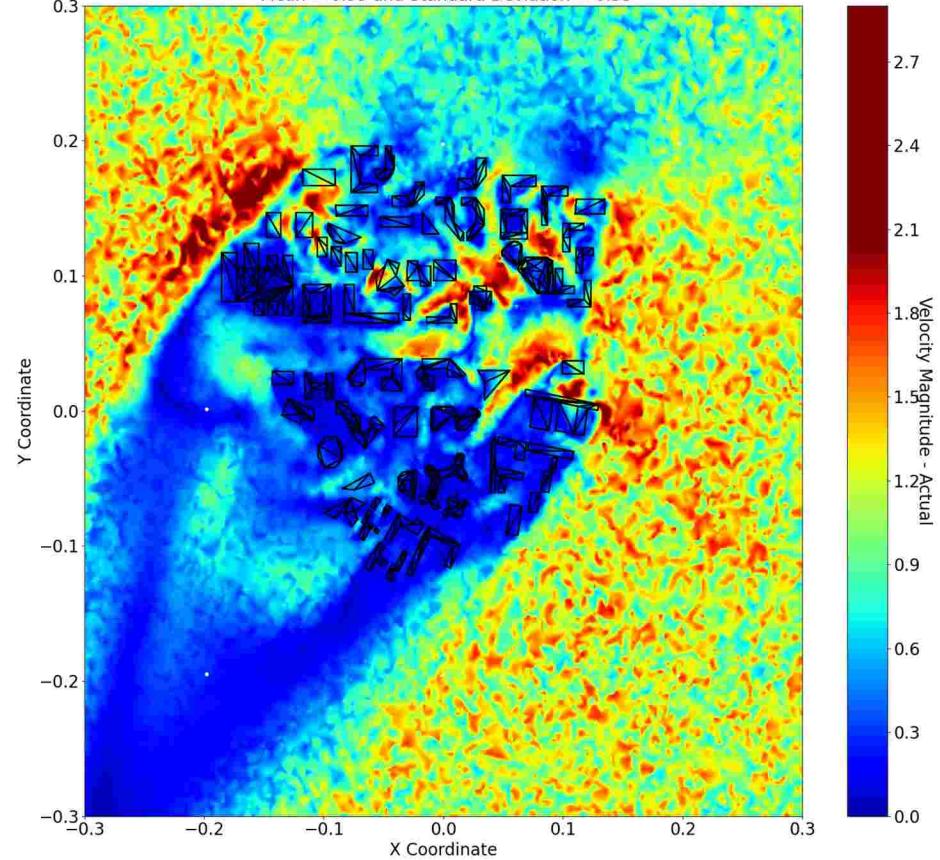


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.49

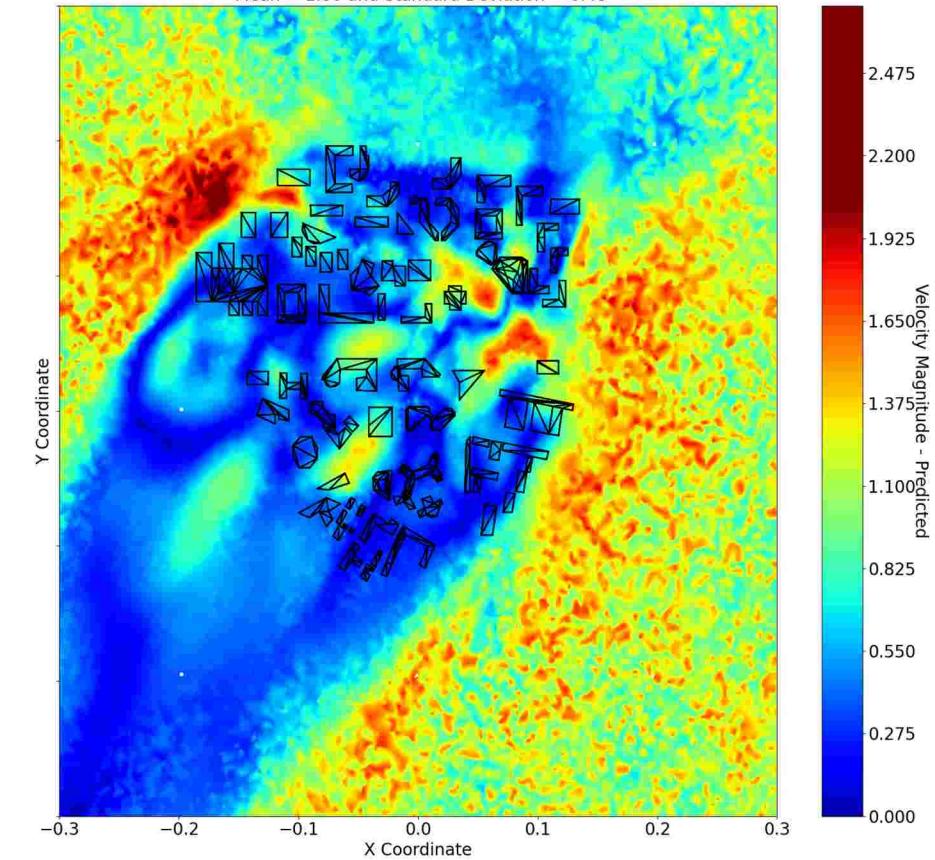


Comparison of Actual vs. Predicted values with Wind Angle = 30 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01
Mean = 0.99 and Standard Deviation = 0.53

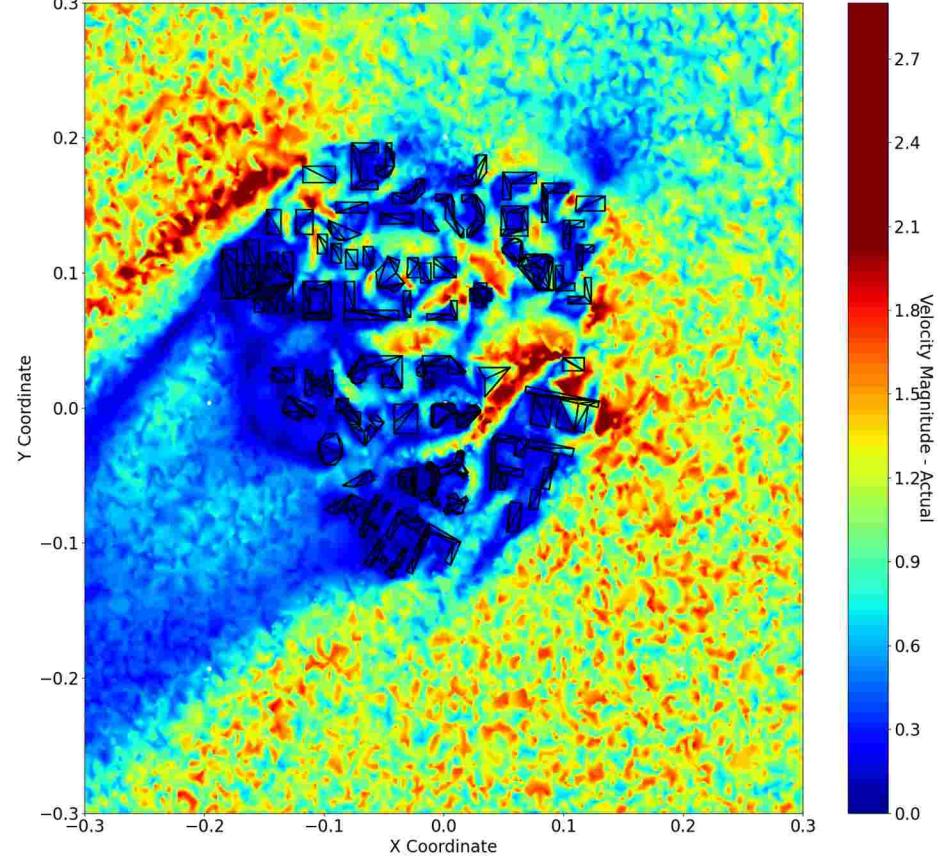


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01
Mean = 1.00 and Standard Deviation = 0.48

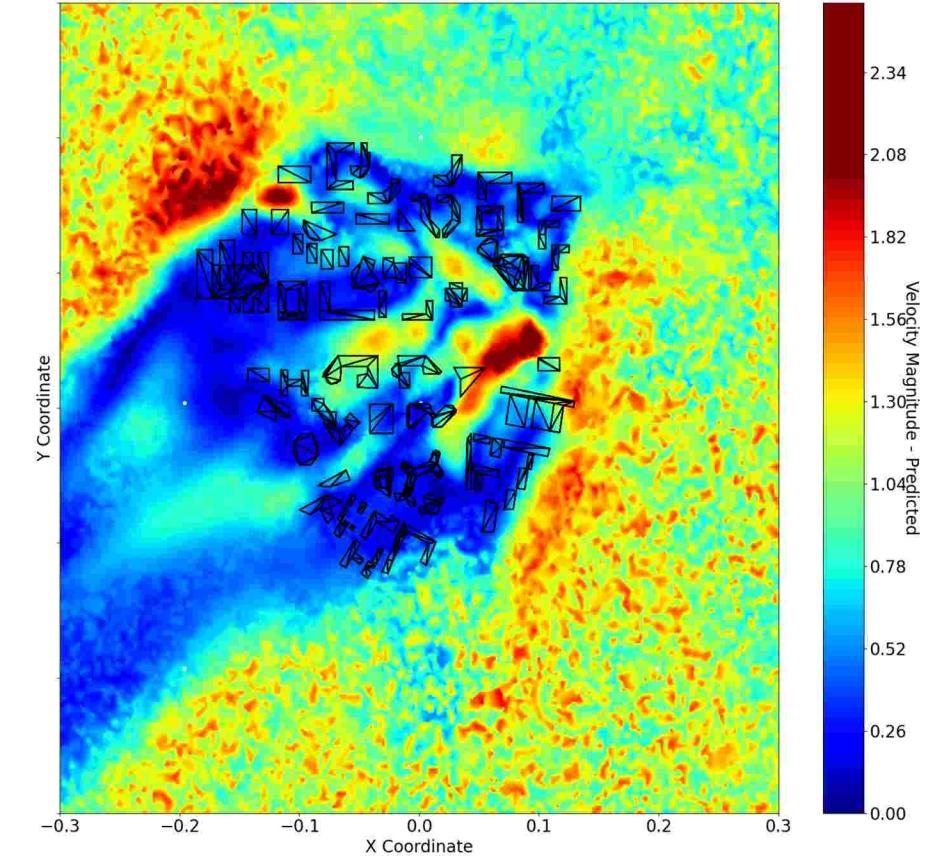


Comparison of Actual vs. Predicted values with Wind Angle = 45 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.51

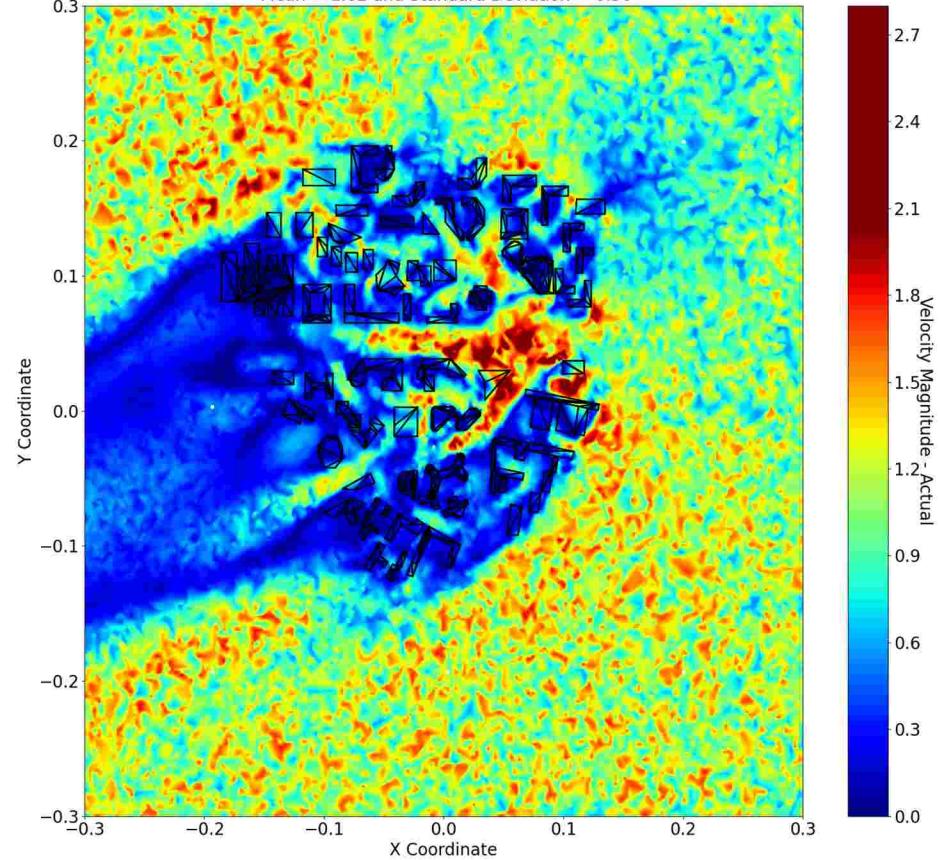


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.01 +/- 0.01
Mean = 1.05 and Standard Deviation = 0.47

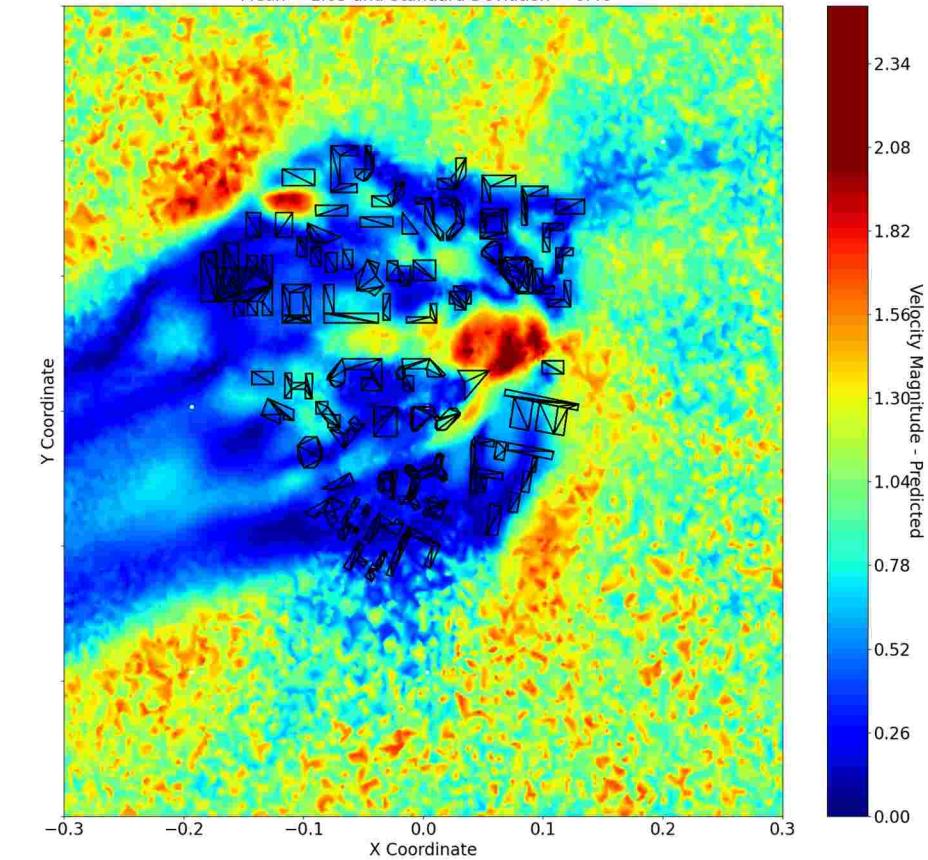


Comparison of Actual vs. Predicted values with Wind Angle = 60 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.50

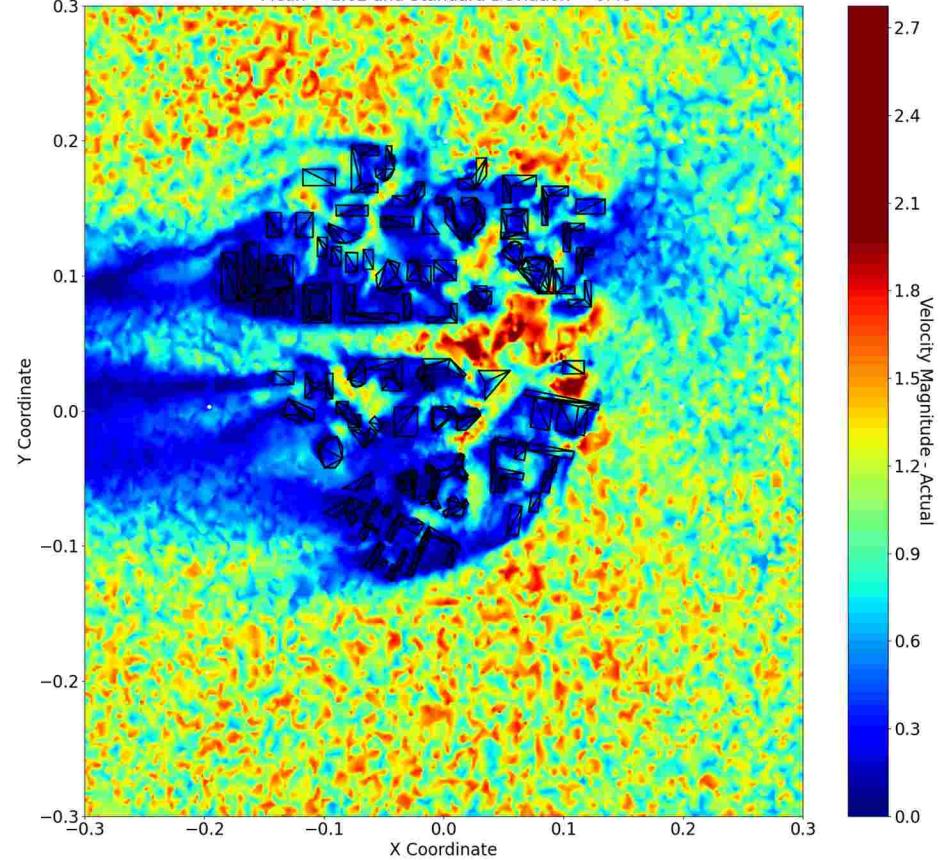


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01
Mean = 1.03 and Standard Deviation = 0.46

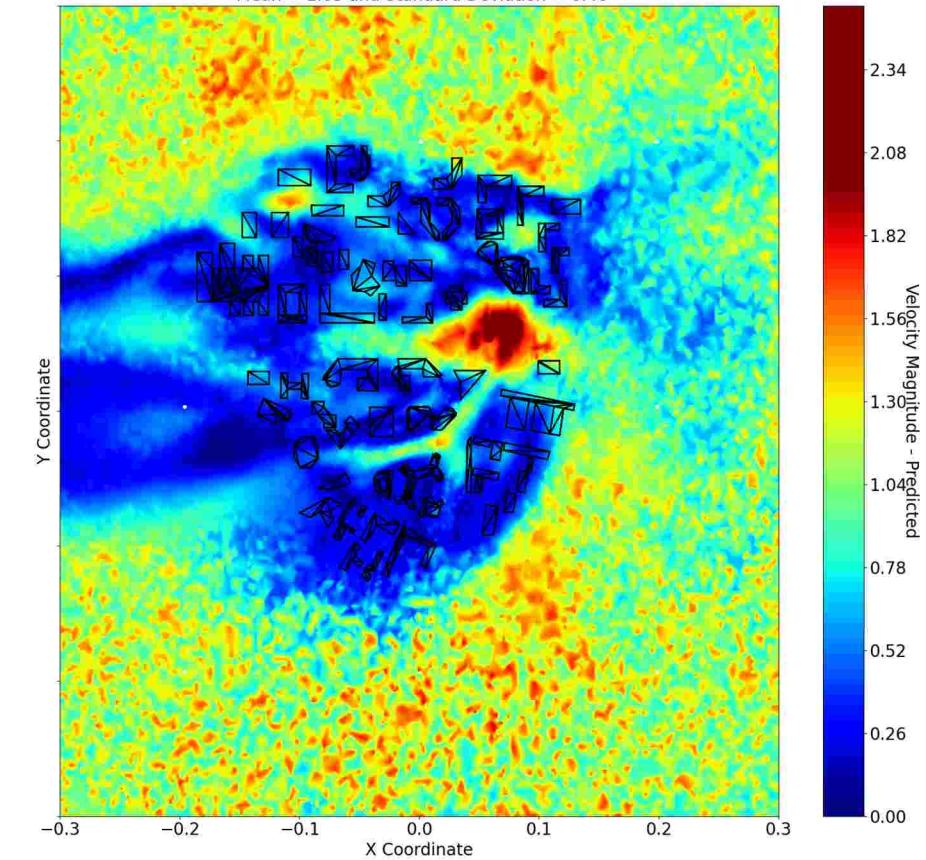


Comparison of Actual vs. Predicted values with Wind Angle = 75 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.48

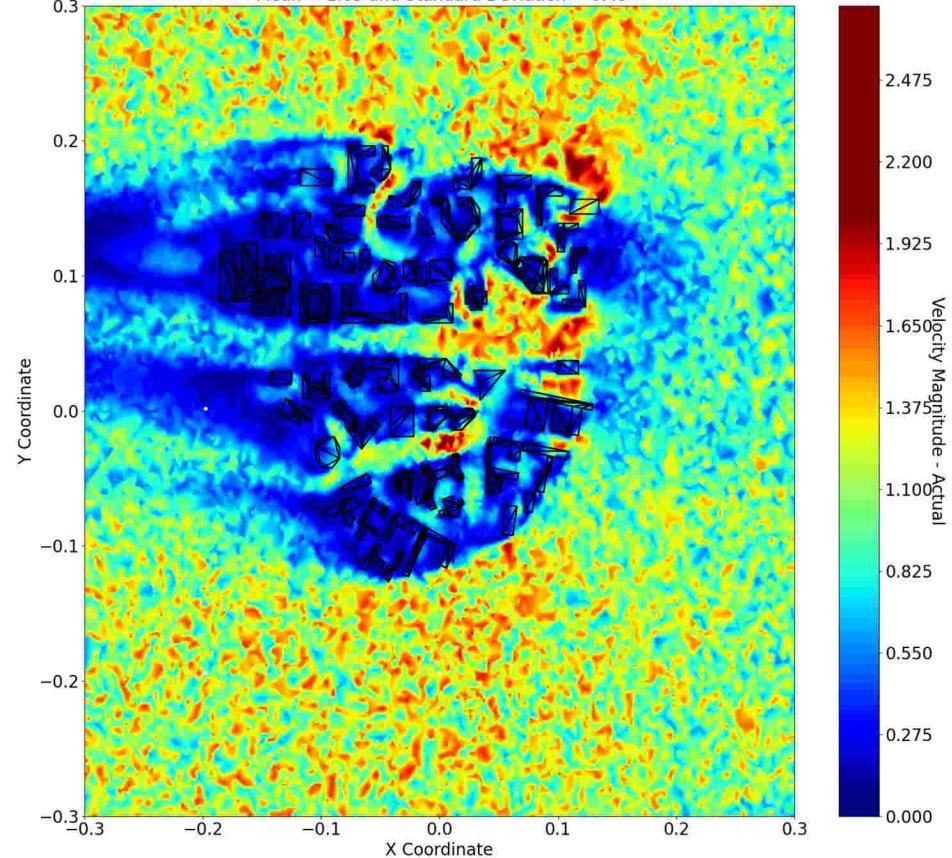


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01
Mean = 1.03 and Standard Deviation = 0.46

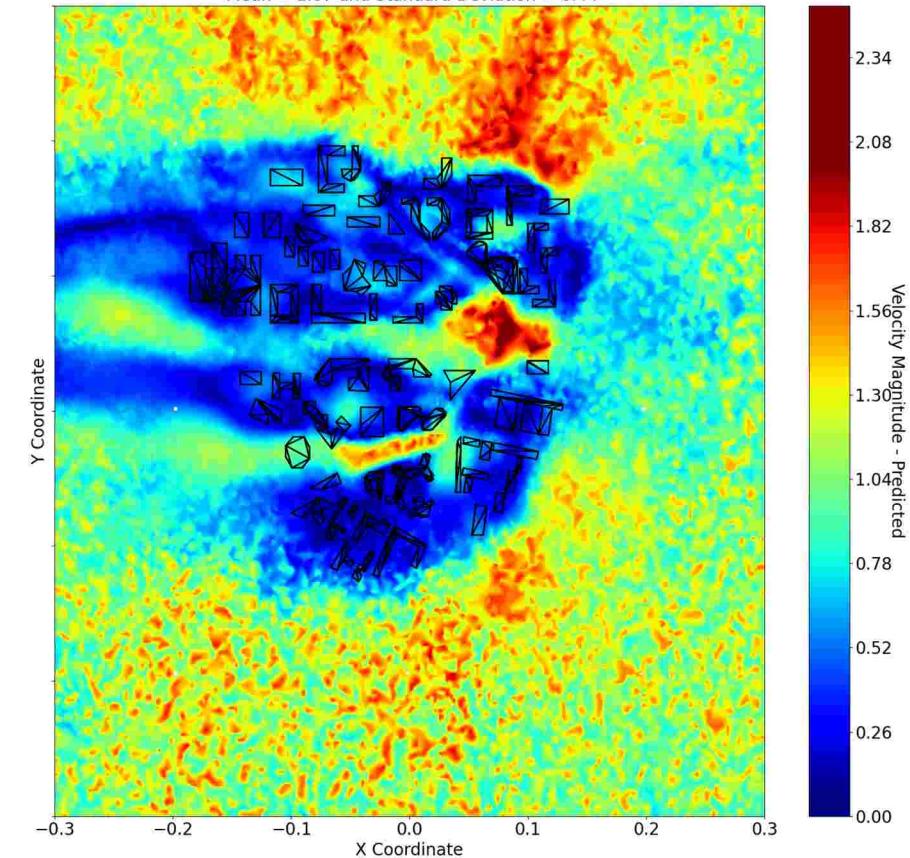


Comparison of Actual vs. Predicted values with Wind Angle = 90 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01
Mean = 1.03 and Standard Deviation = 0.49

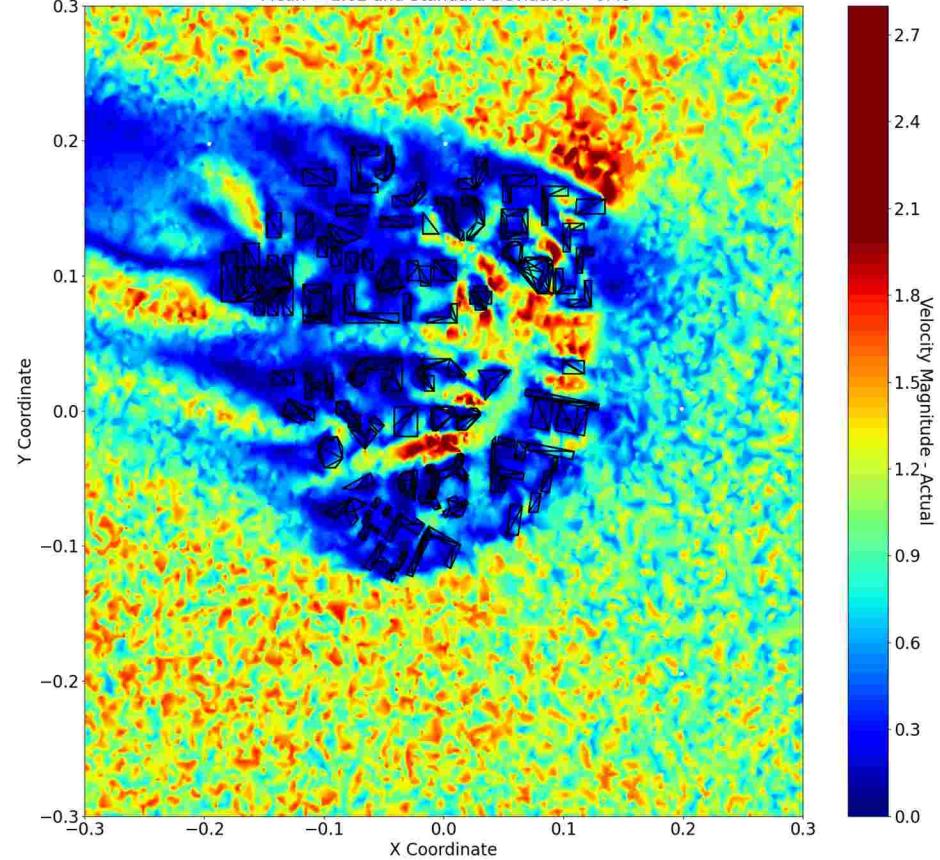


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01
Mean = 1.07 and Standard Deviation = 0.44

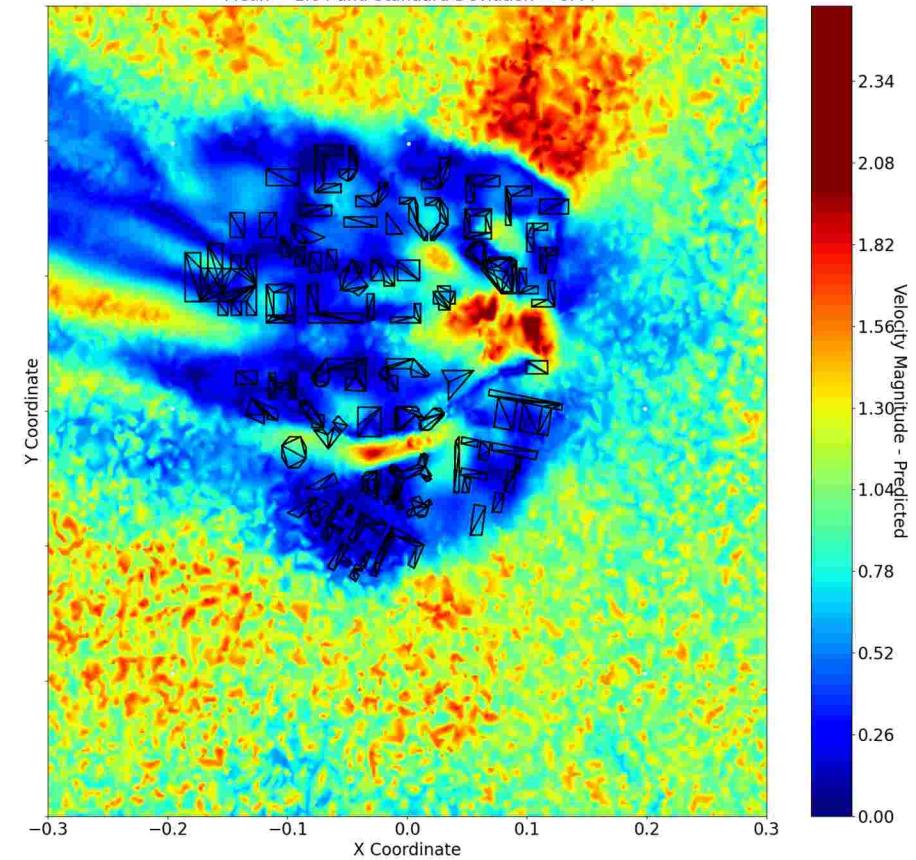


Comparison of Actual vs. Predicted values with Wind Angle = 105 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

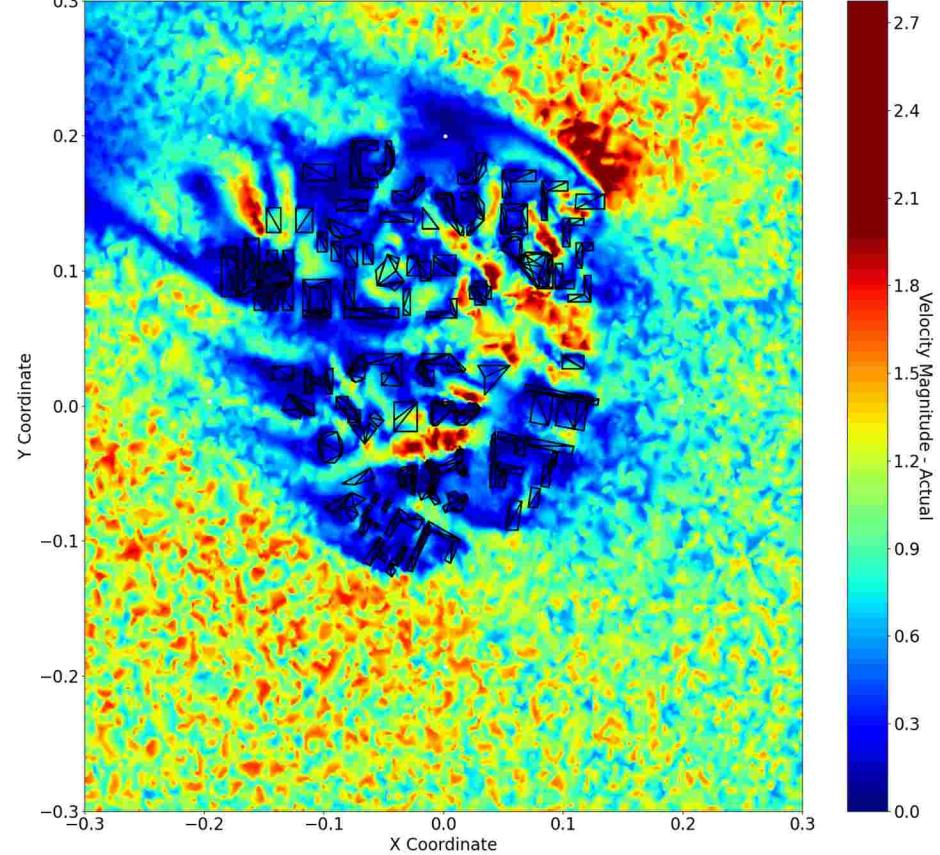


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.44

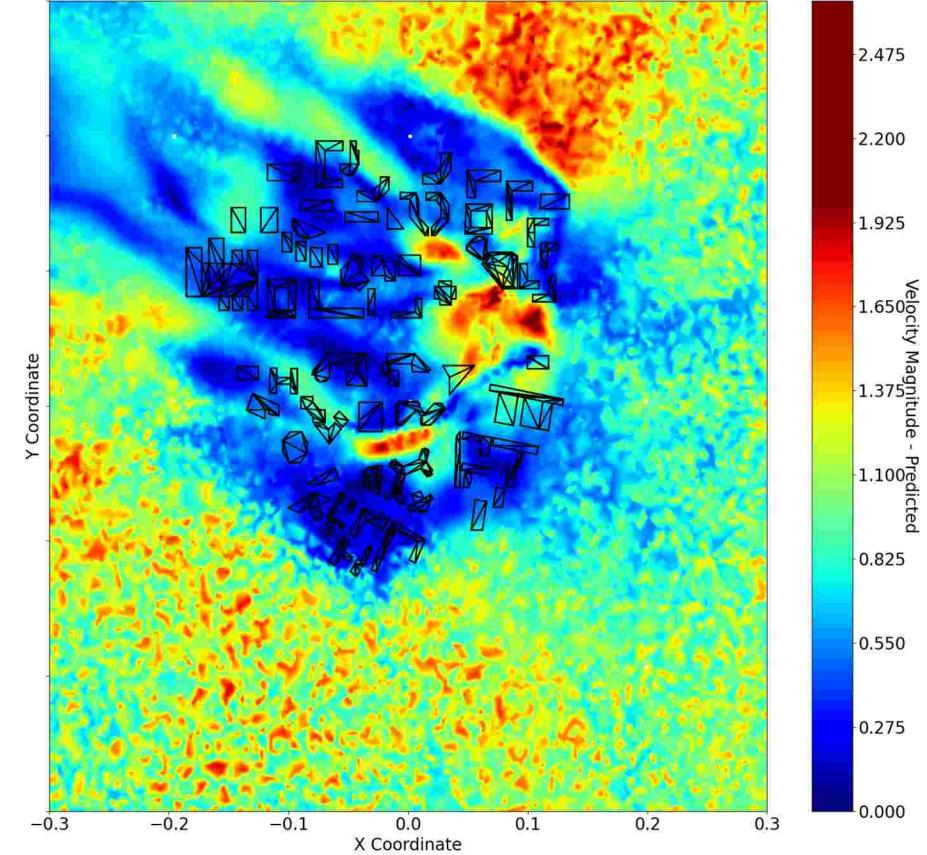


Comparison of Actual vs. Predicted values with Wind Angle = 120 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

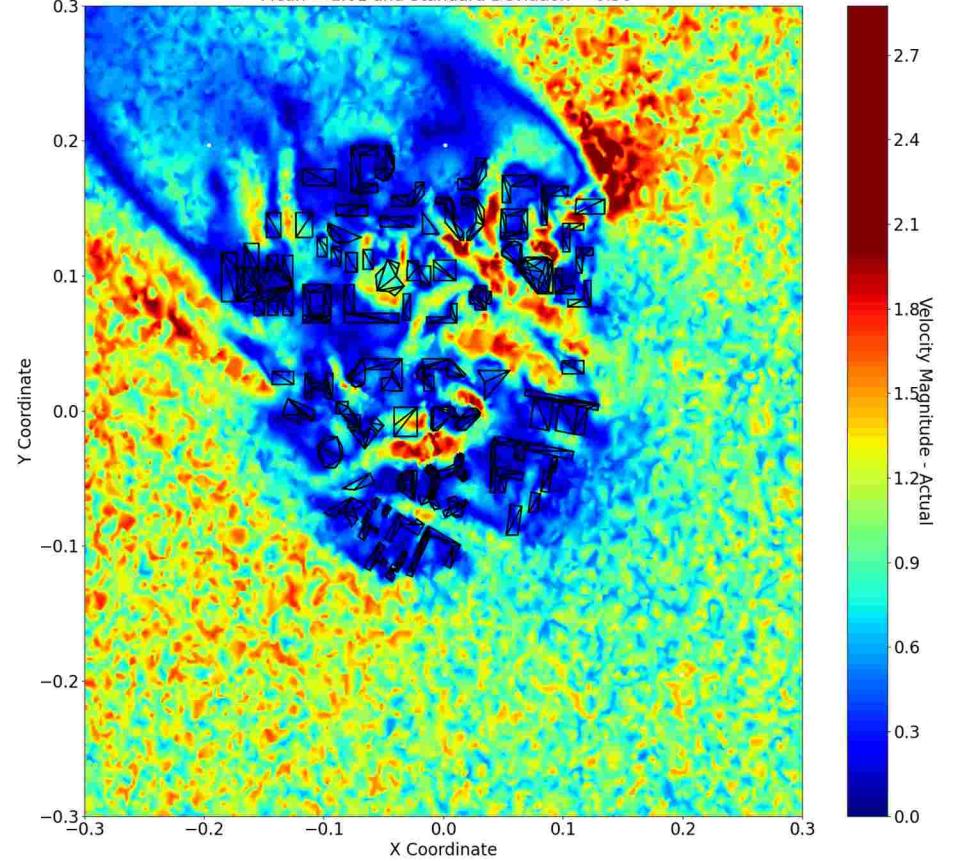


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.44

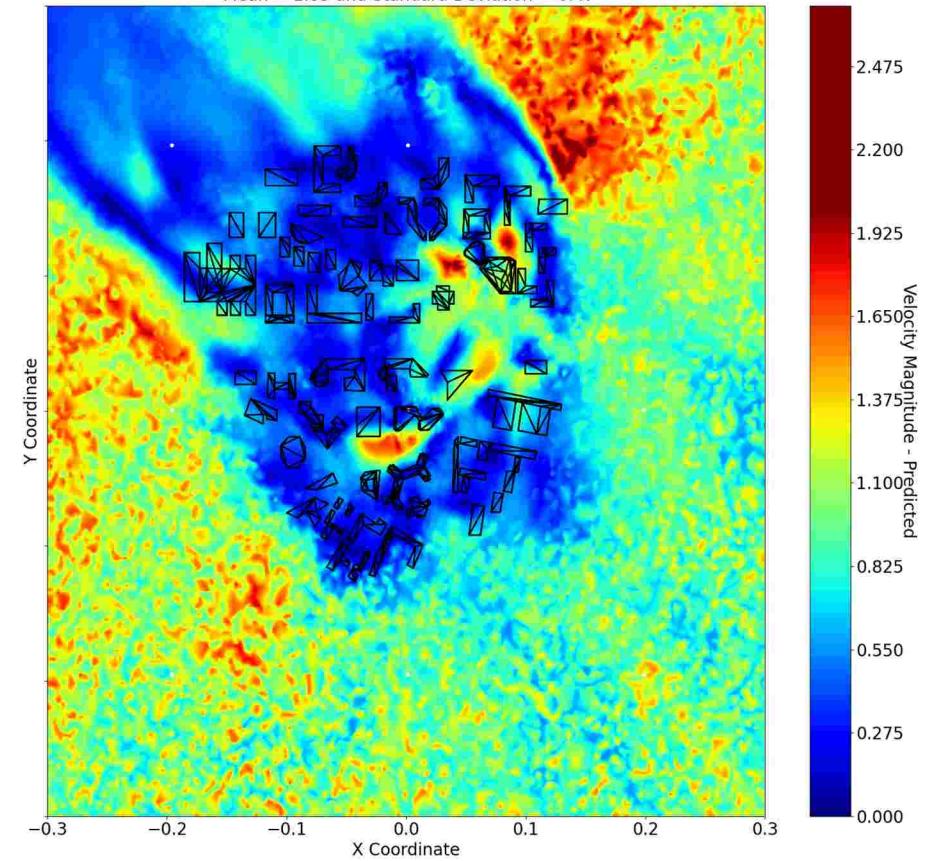


Comparison of Actual vs. Predicted values with Wind Angle = 150 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.50

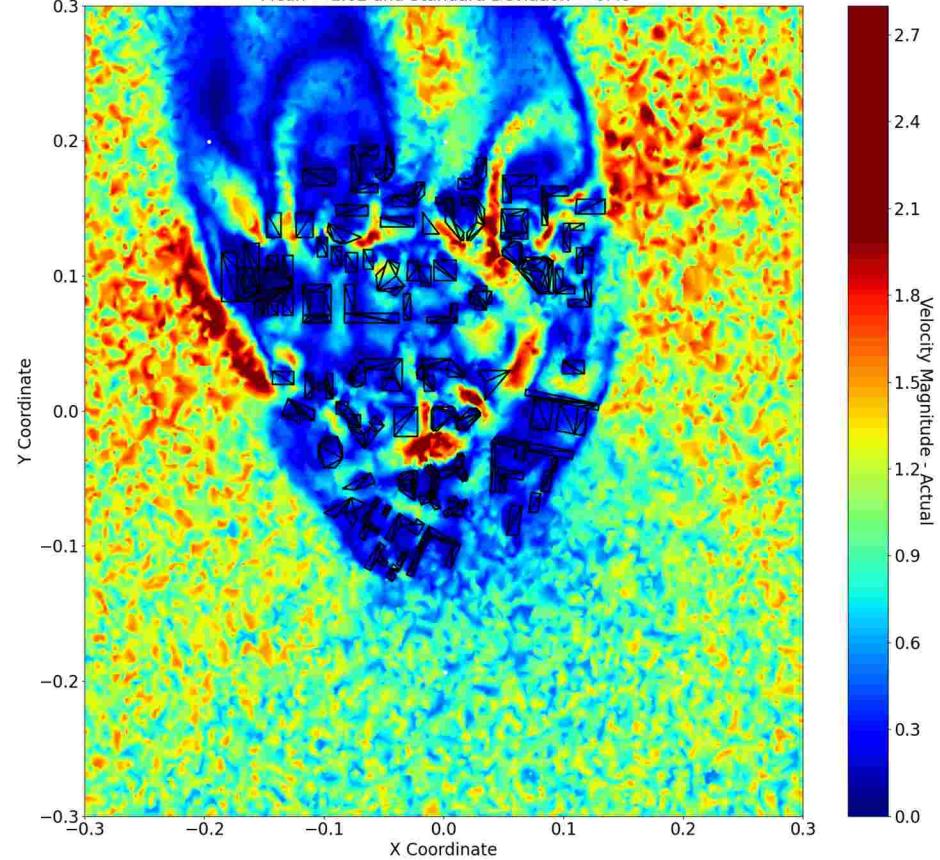


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01
Mean = 1.03 and Standard Deviation = 0.47

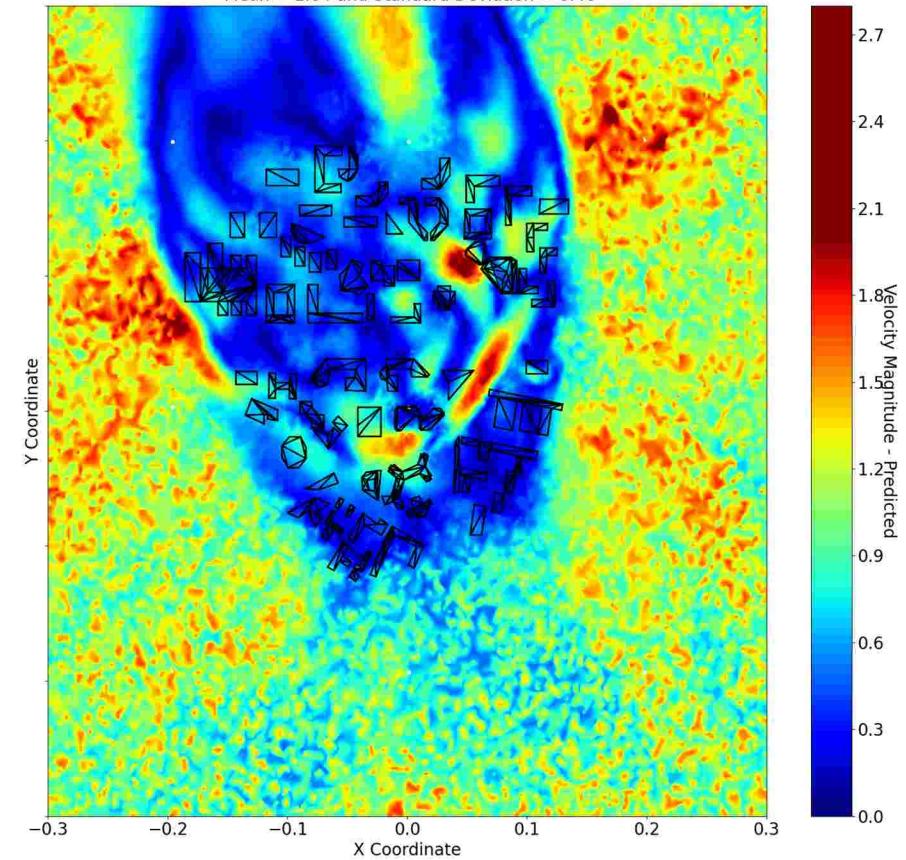


Comparison of Actual vs. Predicted values with Wind Angle = 165 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

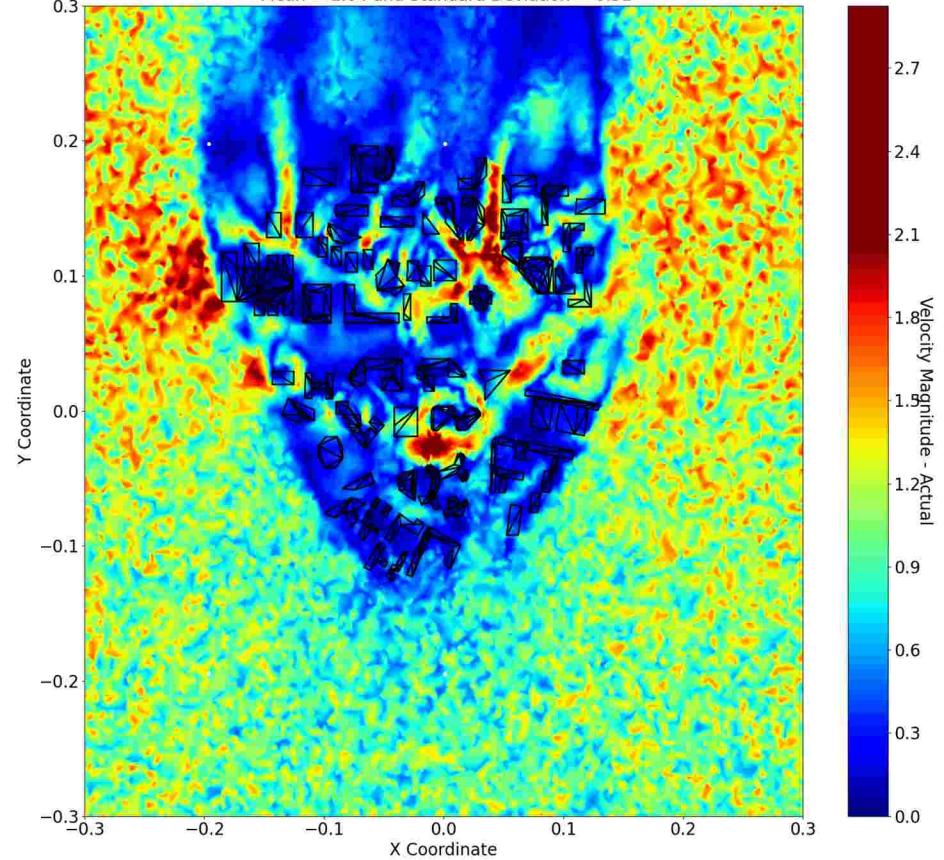


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.46

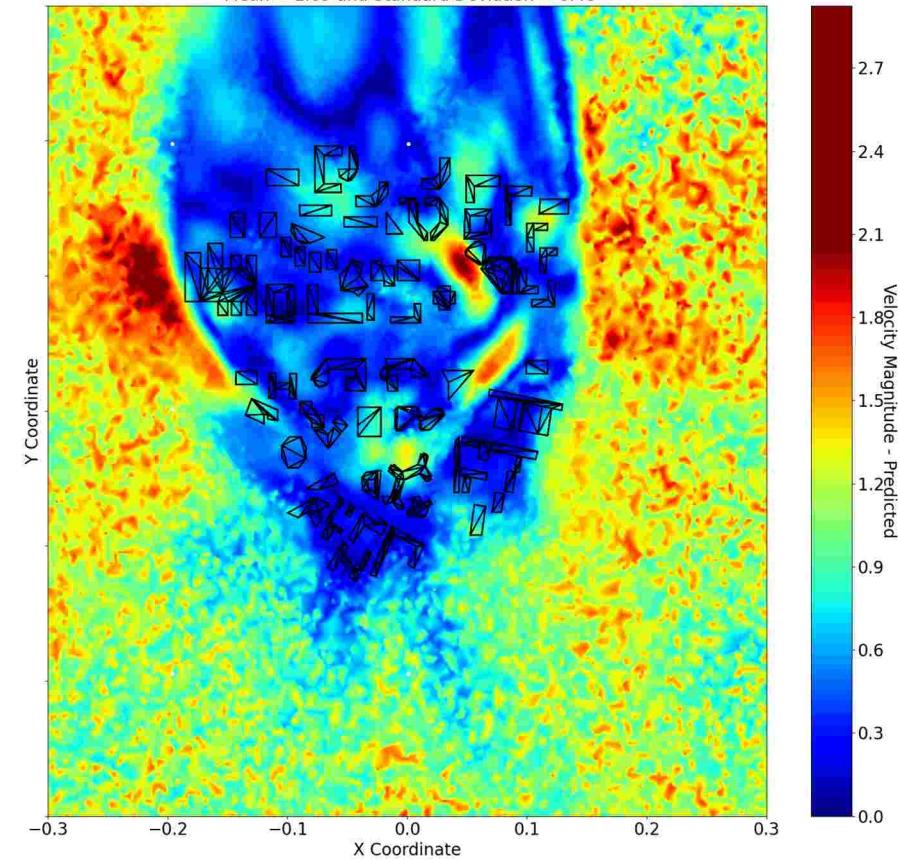


Comparison of Actual vs. Predicted values with Wind Angle = 180 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

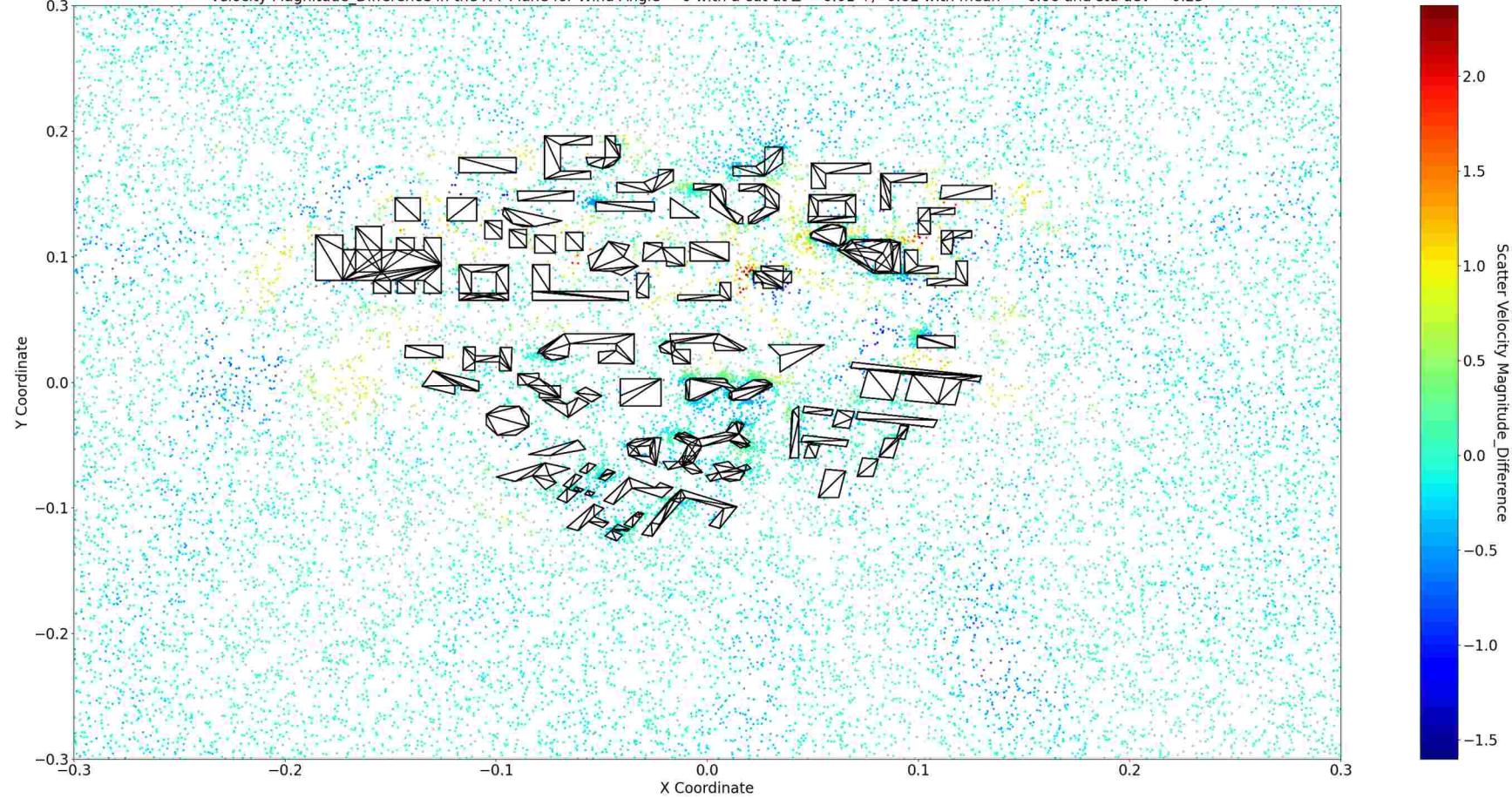
Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.51



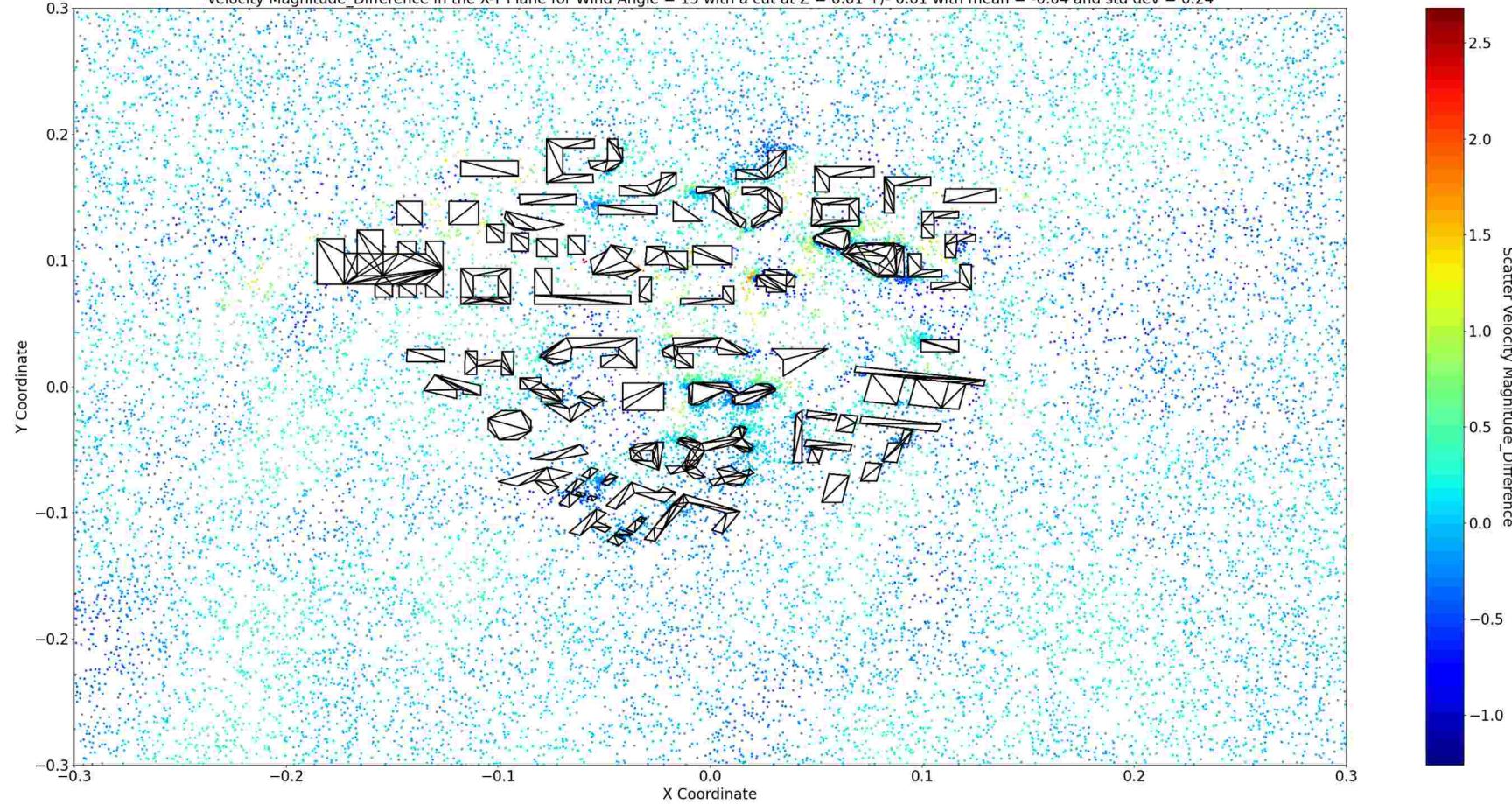
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01
Mean = 1.09 and Standard Deviation = 0.48



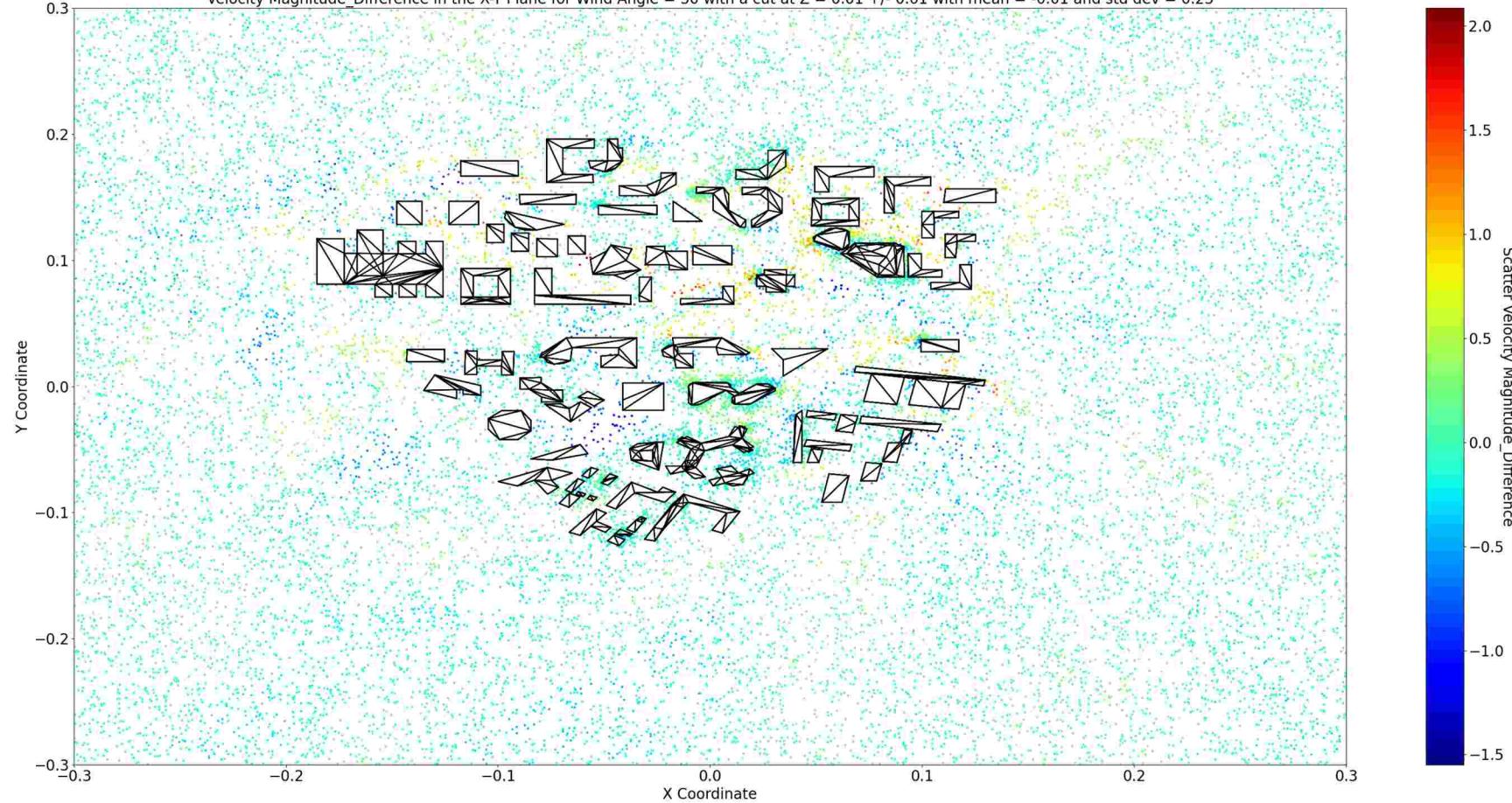
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01 with mean = -0.06 and std dev = 0.25



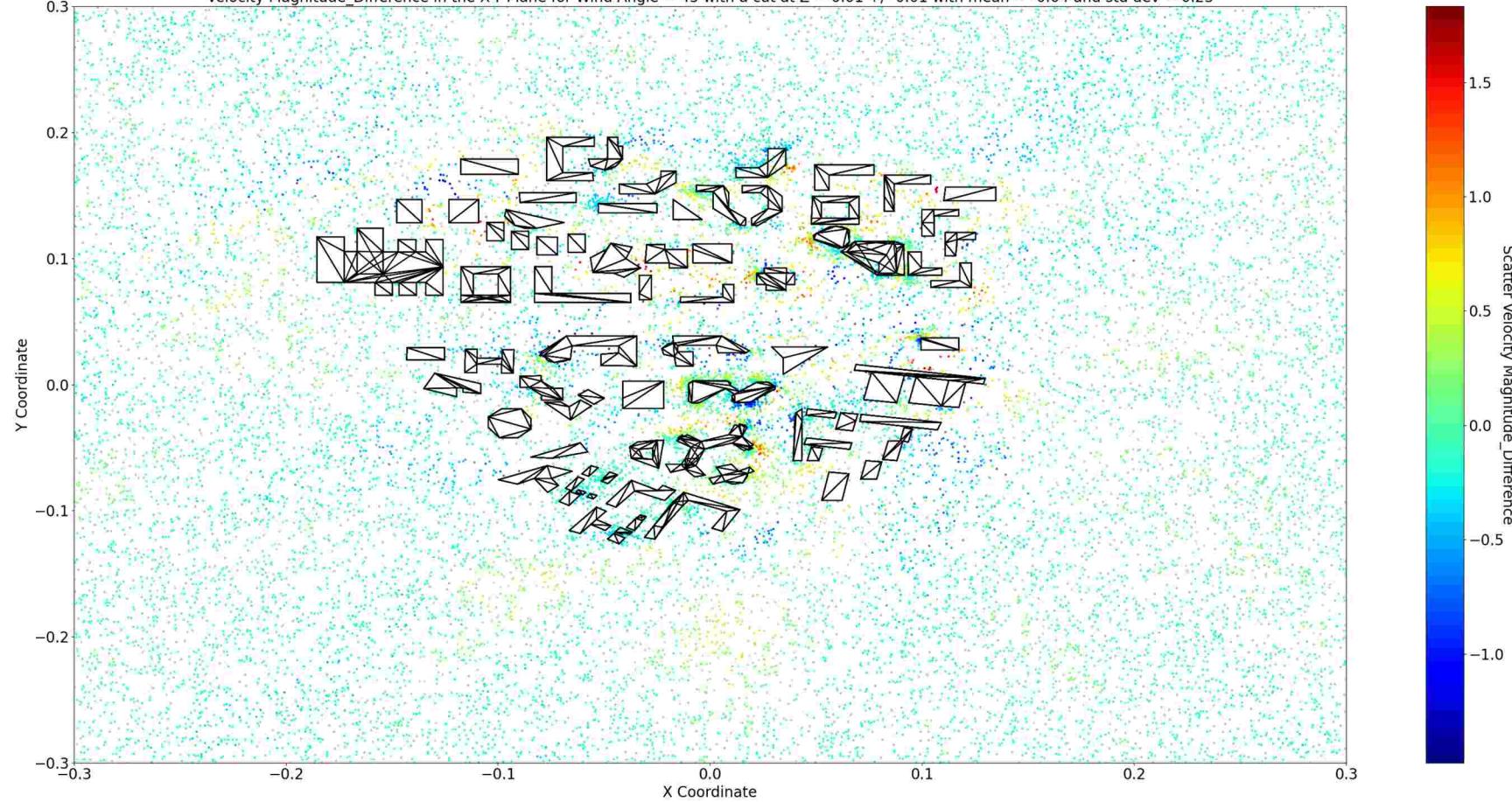
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01 with mean = -0.04 and std dev = 0.24



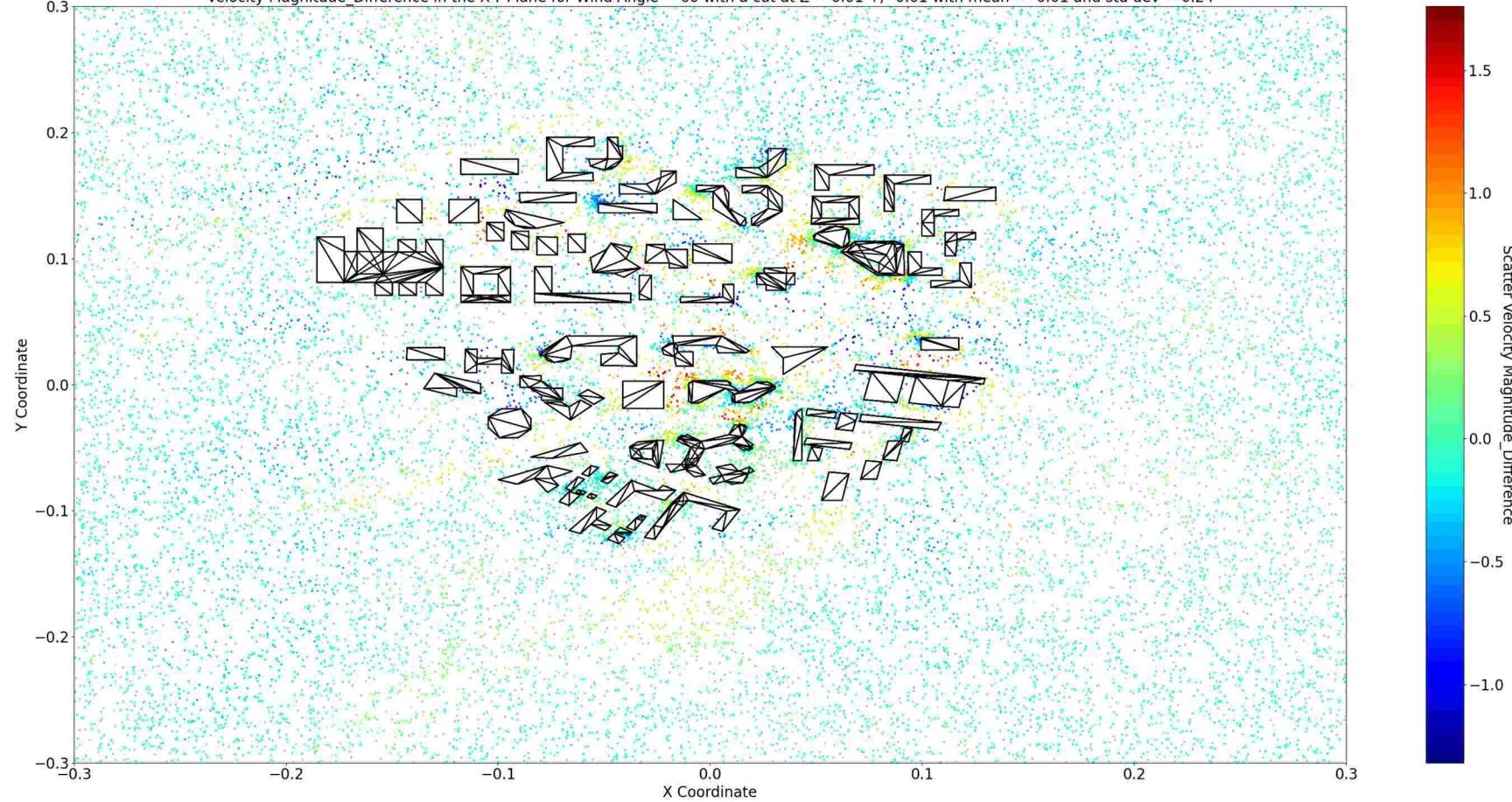
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01 with mean = -0.01 and std dev = 0.23



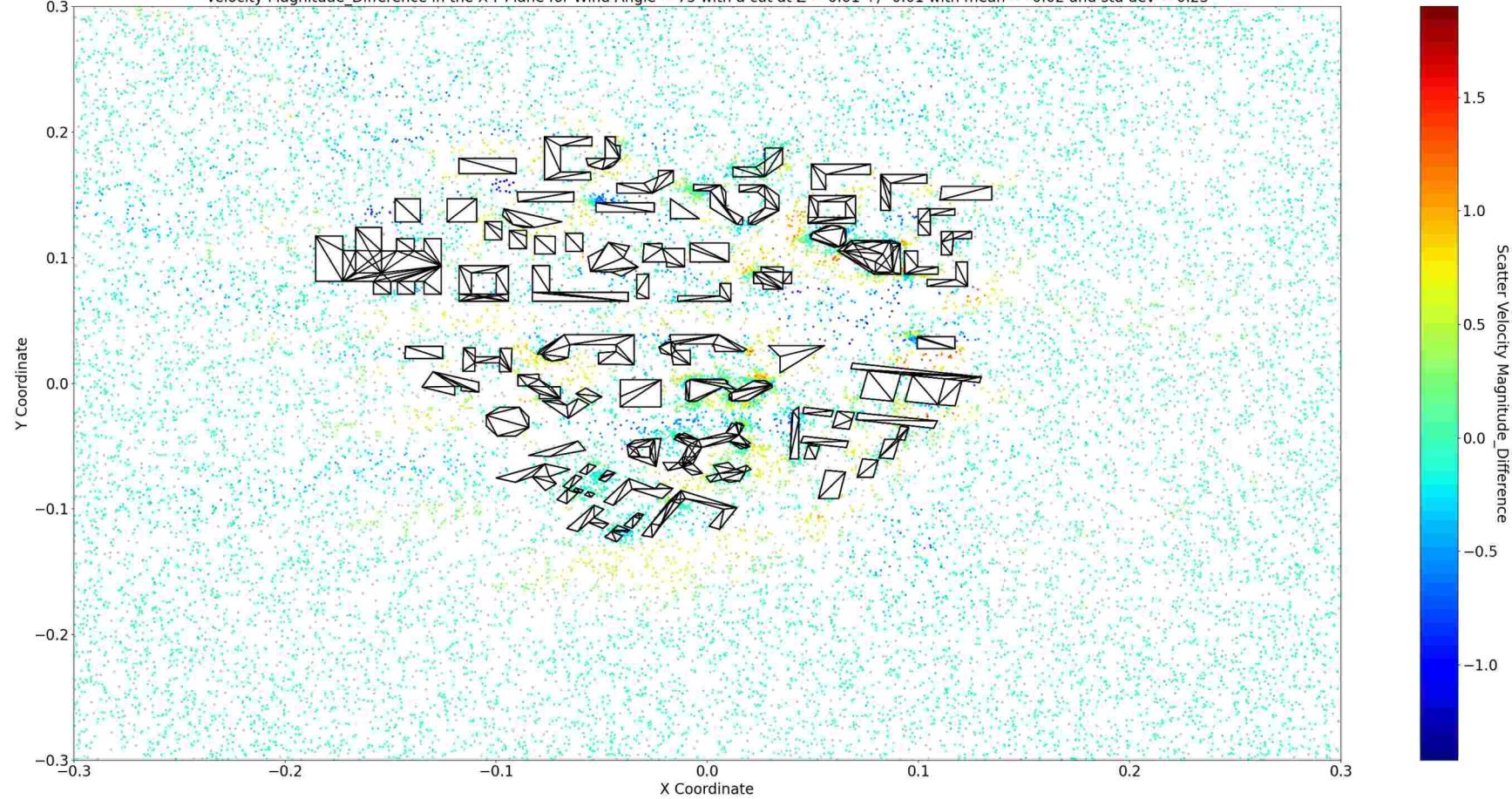
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.01 +/- 0.01 with mean = -0.04 and std dev = 0.23



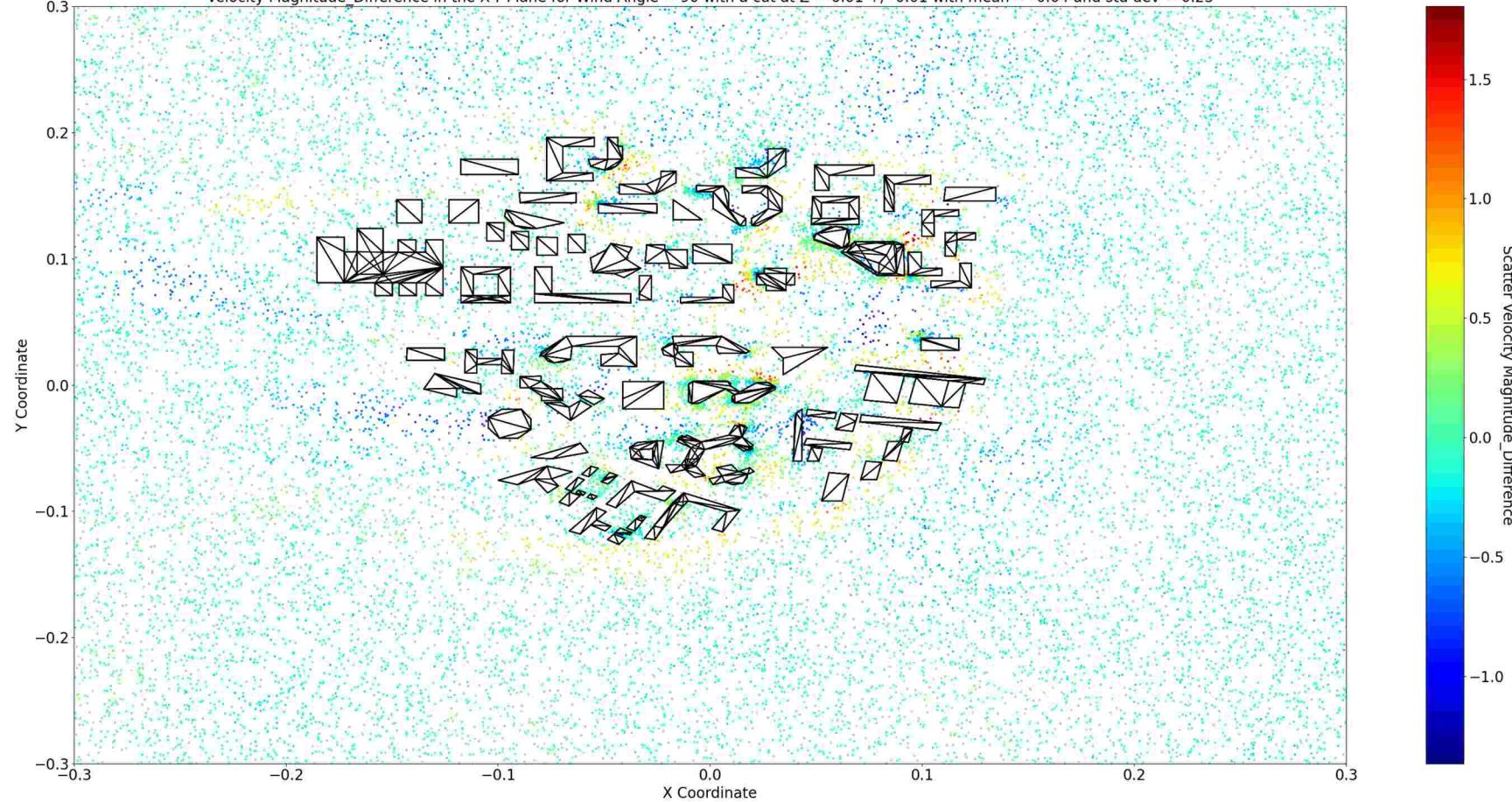
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01 with mean = -0.01 and std dev = 0.24



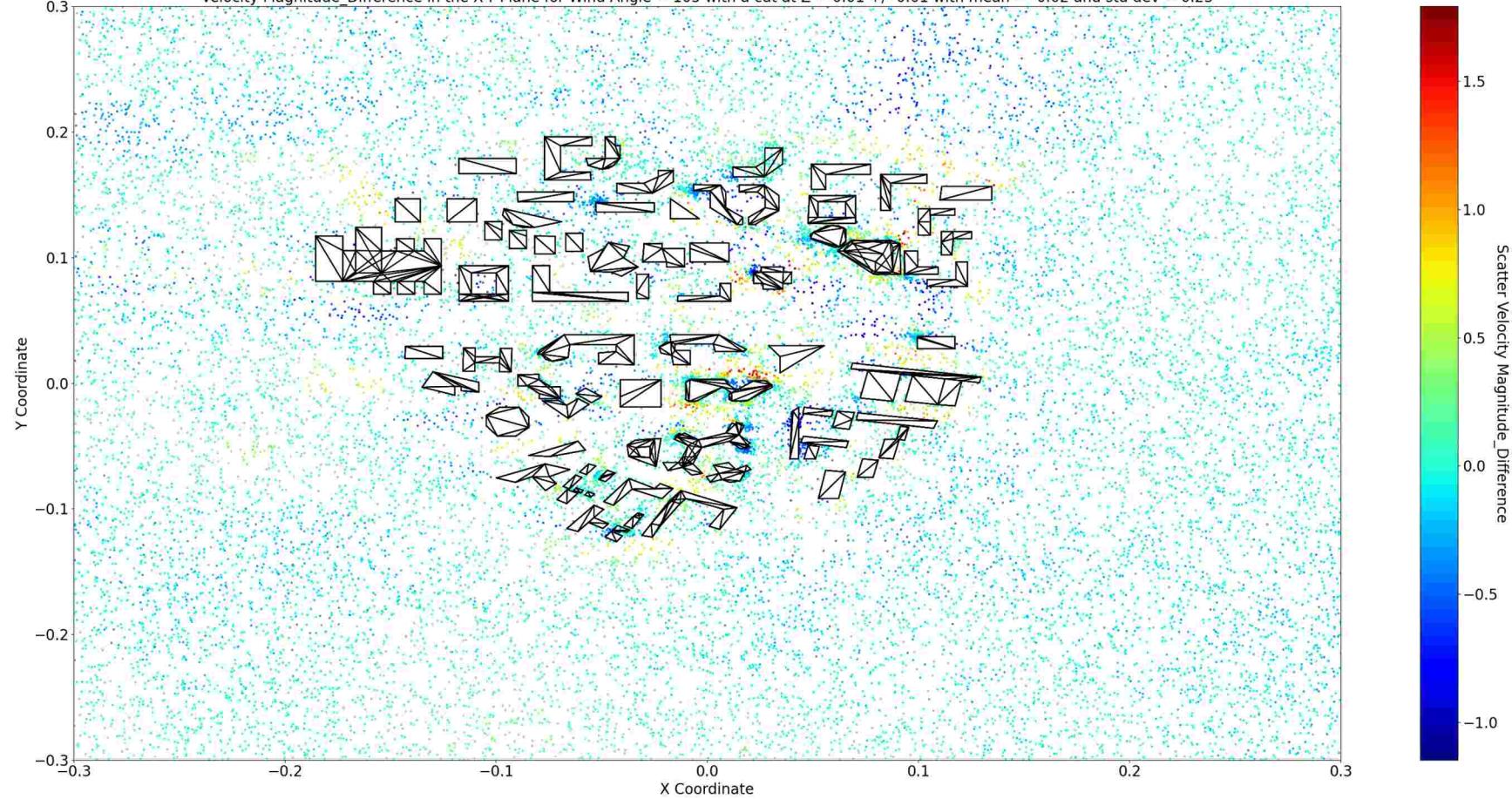
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01 with mean = -0.02 and std dev = 0.23



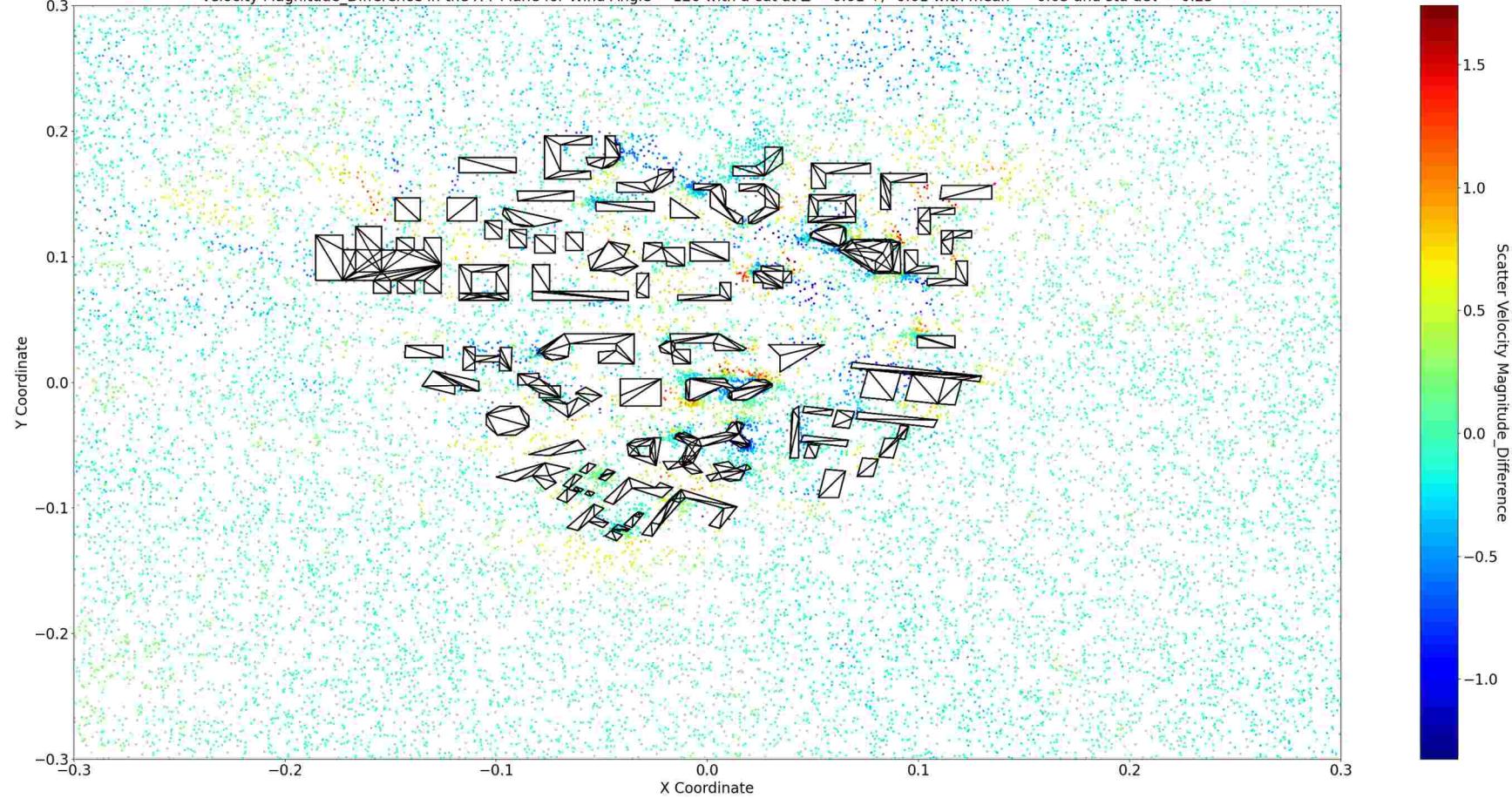
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01 with mean = -0.04 and std dev = 0.23



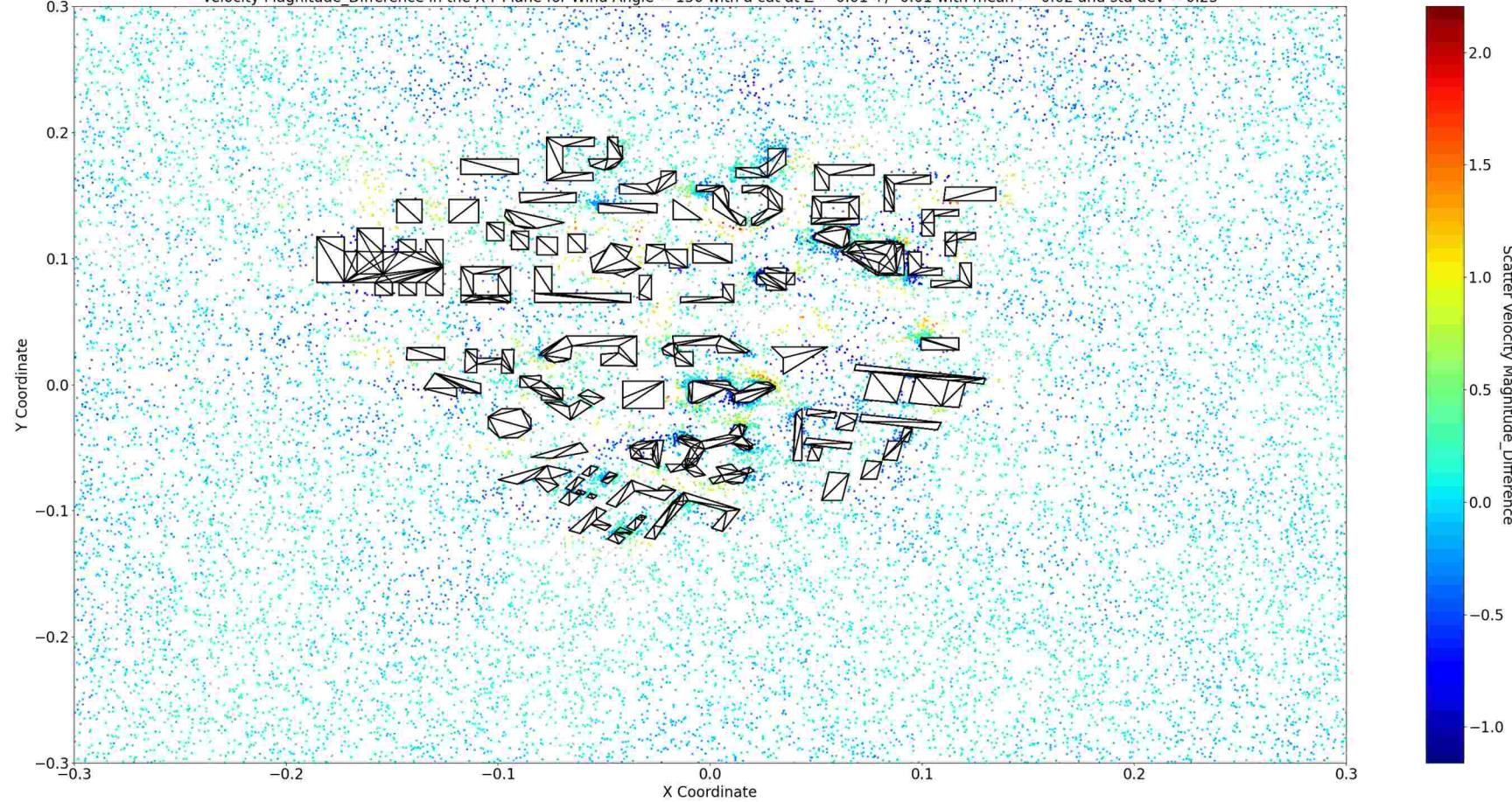
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01 with mean = -0.02 and std dev = 0.23



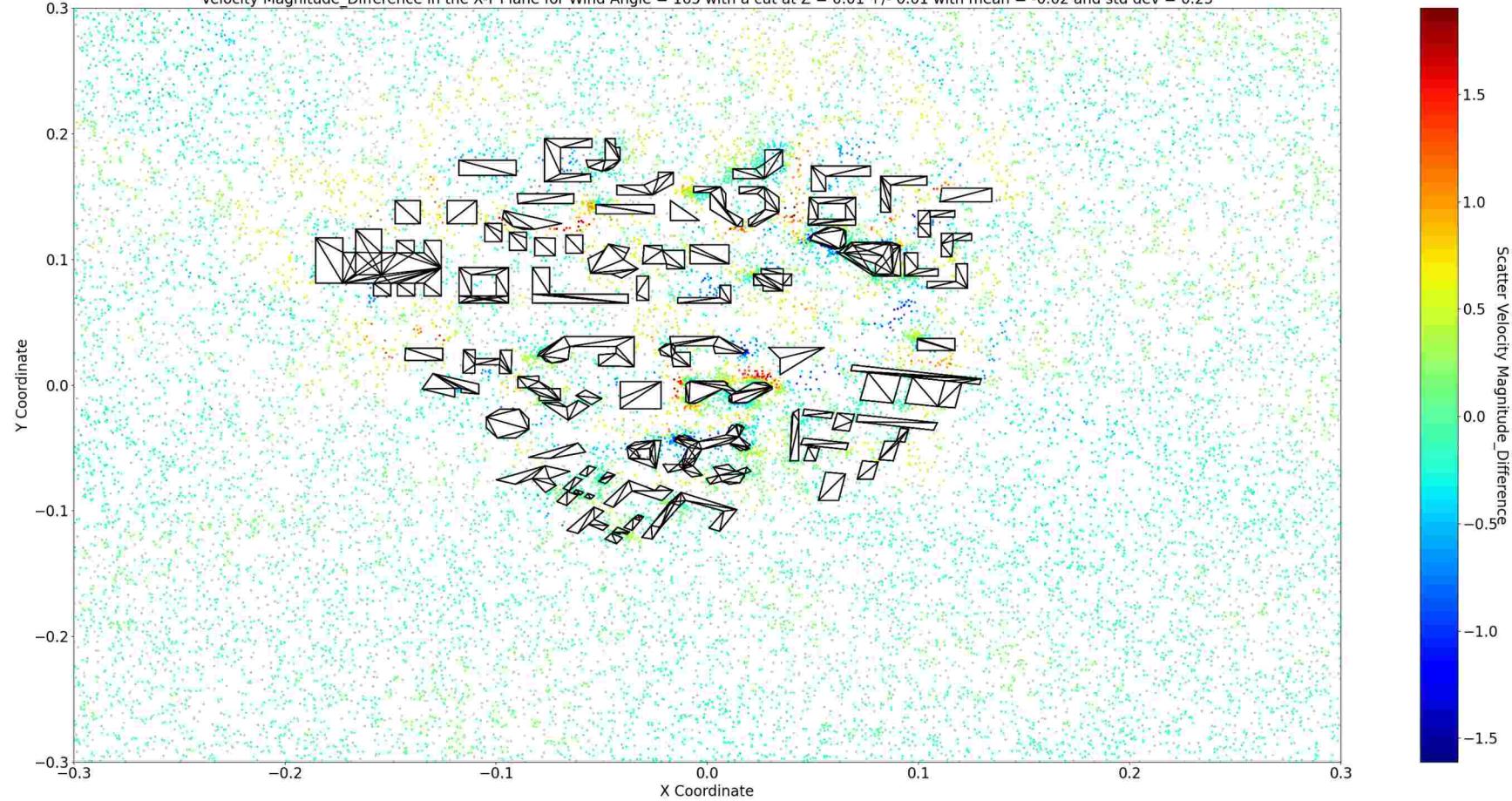
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01 with mean = -0.03 and std dev = 0.25



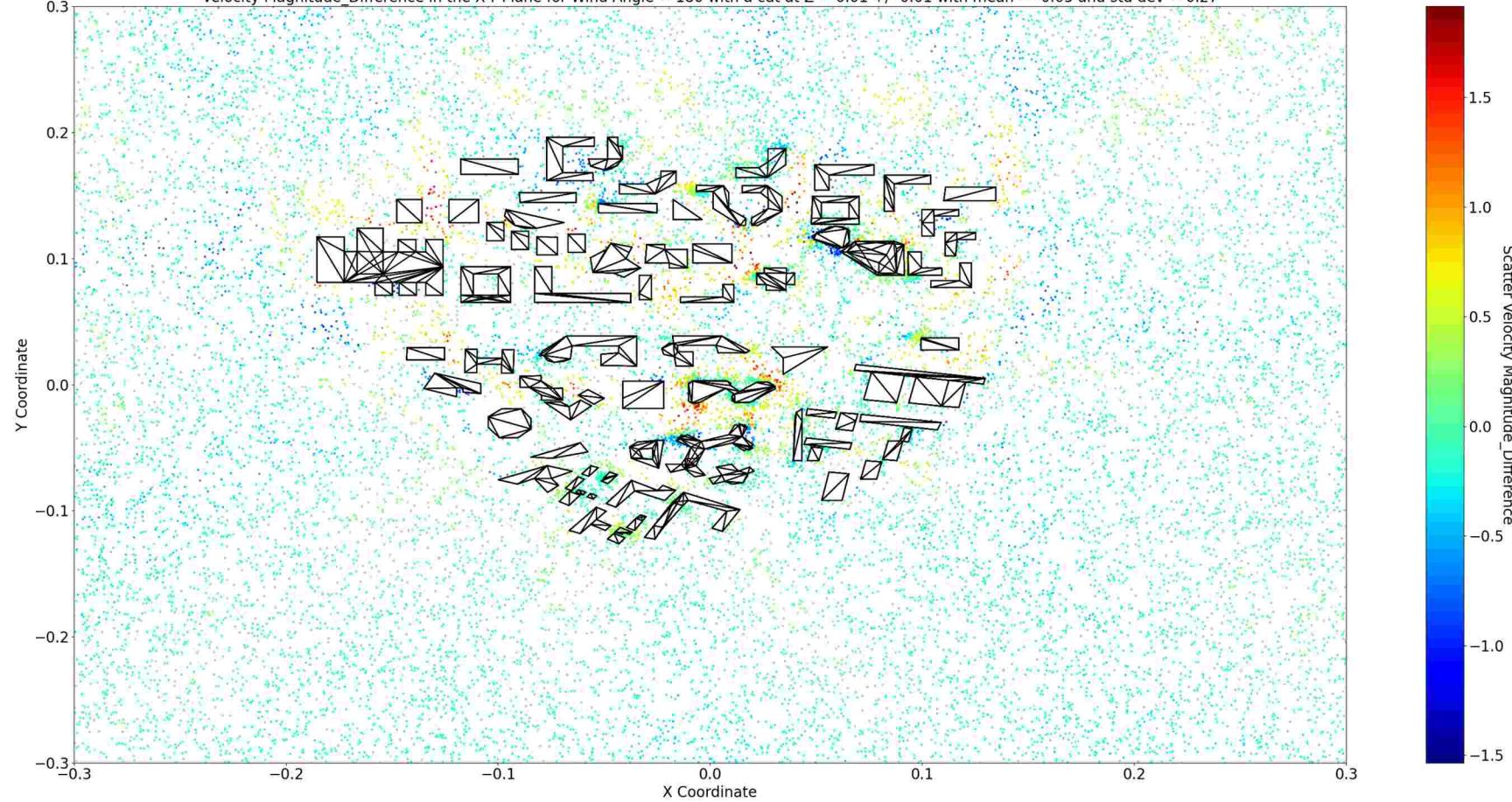
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01 with mean = -0.02 and std dev = 0.25



Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01 with mean = -0.02 and std dev = 0.25



Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01 with mean = -0.05 and std dev = 0.27



Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (121 Epochs, not completed), Full Dataset, GPU Workstation

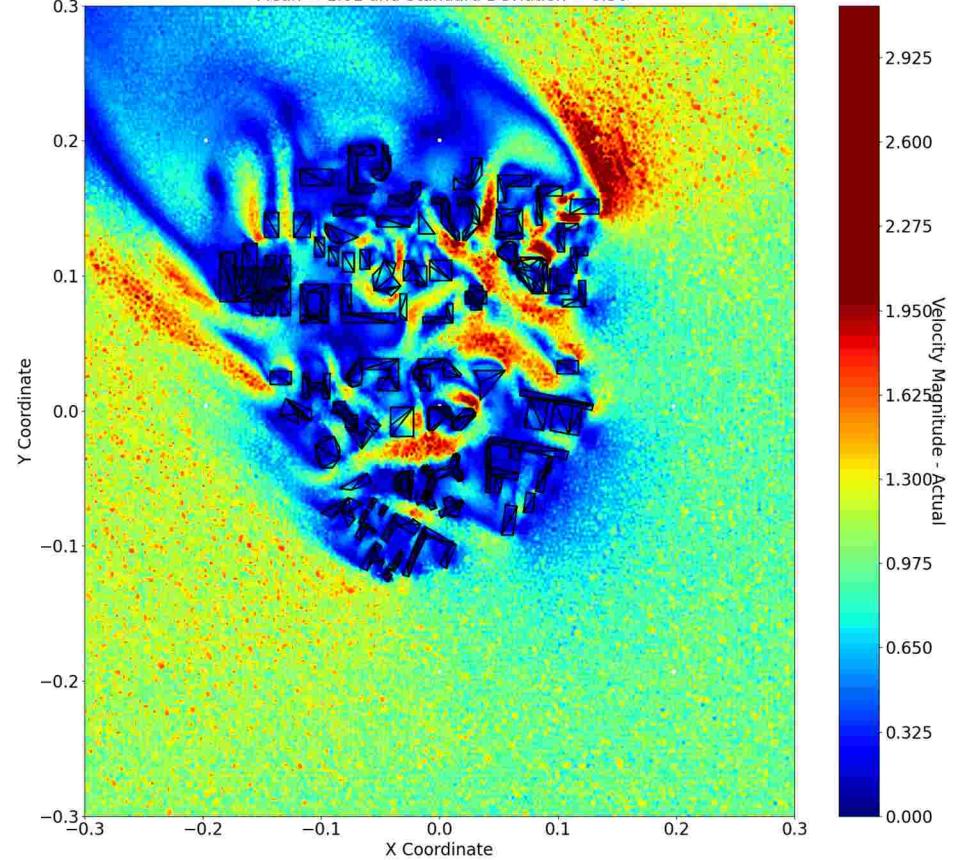
Scripts v5 – PREDICTING

Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), GPU Workstation
Predicting Results – Metrics (Angle = 135)

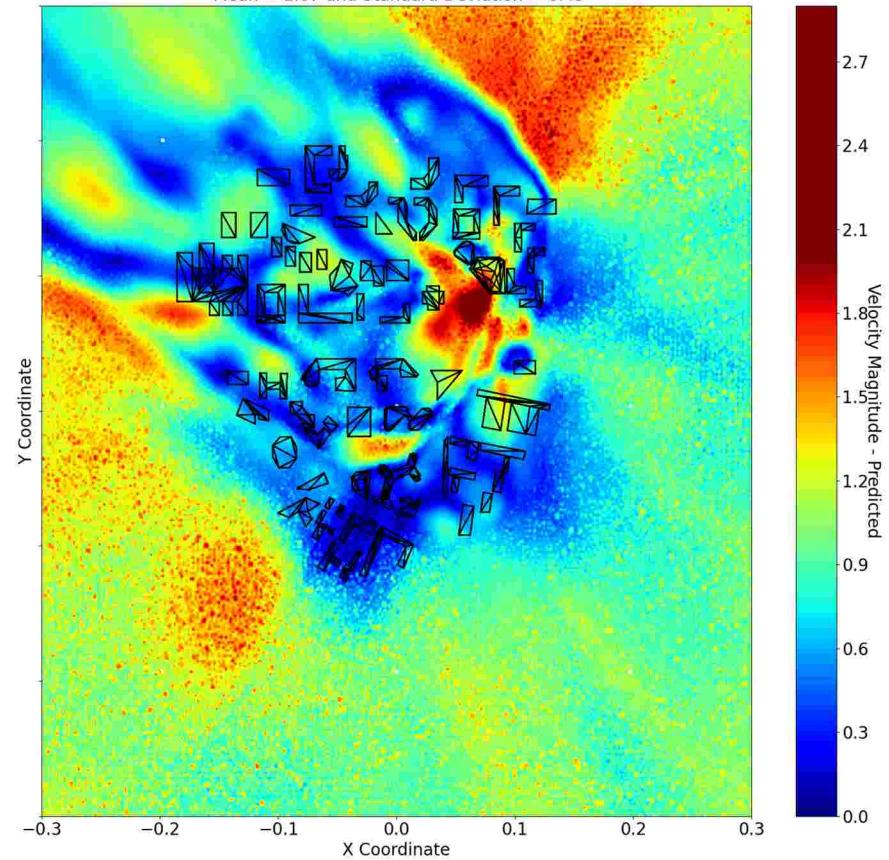
Variable	MSE	RMSE	MAE	R2
Velocity:0	0.211579	0.4599776	0.408023	0.803948
Velocity:1	0.201545	0.4489379	0.3748347	0.823210
Velocity:2	0.007911	0.0889450	0.0354154	0.5849466

Comparison of Actual vs. Predicted values with Wind Angle = 135 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

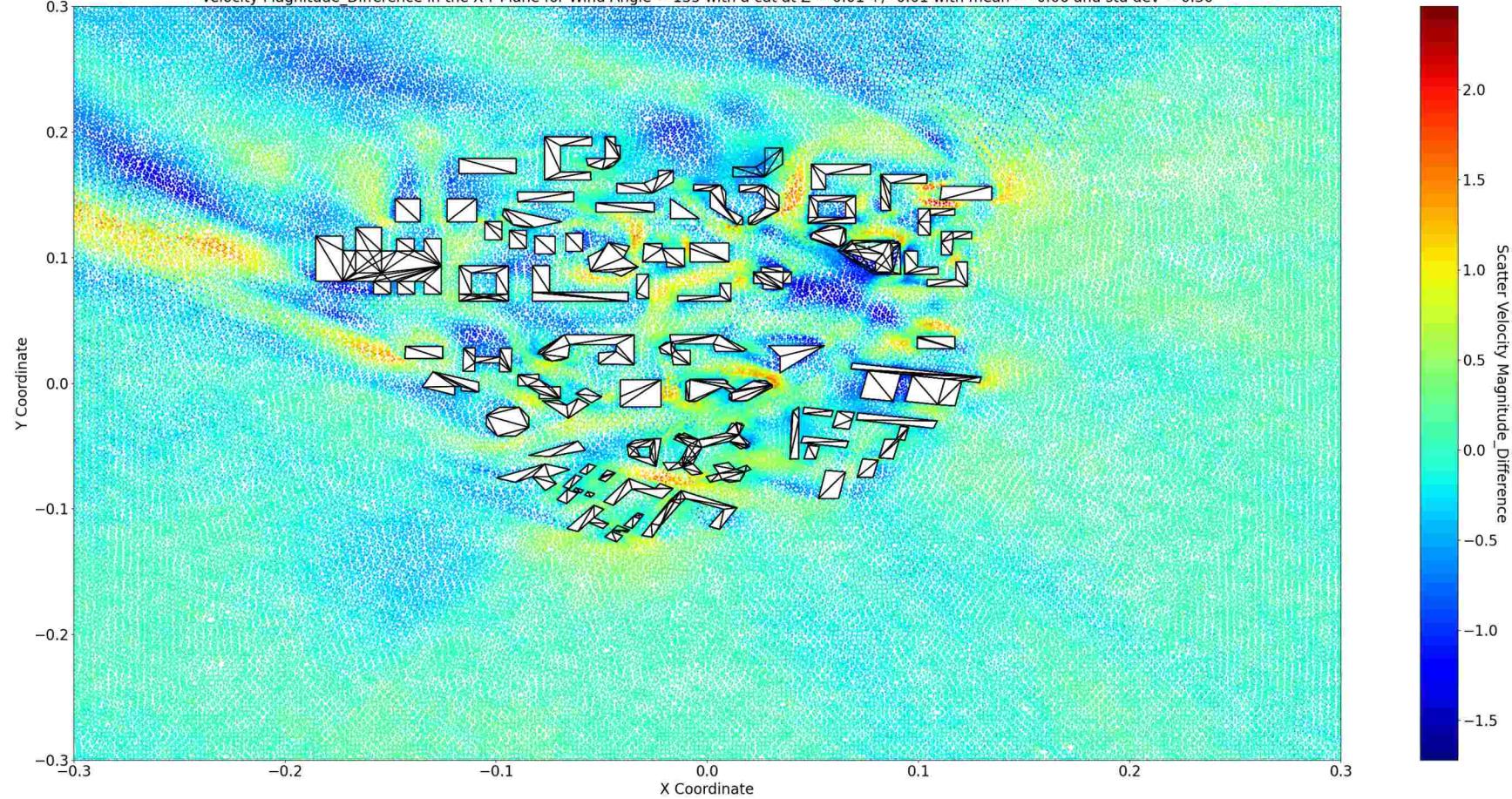
Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.50



Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01
Mean = 1.07 and Standard Deviation = 0.45



Velocity Magnitude_Difference in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01 with mean = -0.06 and std dev = 0.30



Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (800 Epochs, not completed), Reduced, GPU Laptop

Scripts v5 – TESTING

Some Parameters

Infinite epochs - Simple Moving Average stopping condition

128 Neurons for the PINN unless otherwise specified (50949 parameters in total)

We have the data for 13 angles, [0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180] in degrees

We concatenate the data for angles = [0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180] and then take 99% of the dataset with random seed = 42 for training and 1% for testing

By using 99% of the whole dataset we hope to make the NN learn about wind angle such that the parameters become functions of the wind angle

Then using the trained neural network we predict the data for angle = 135

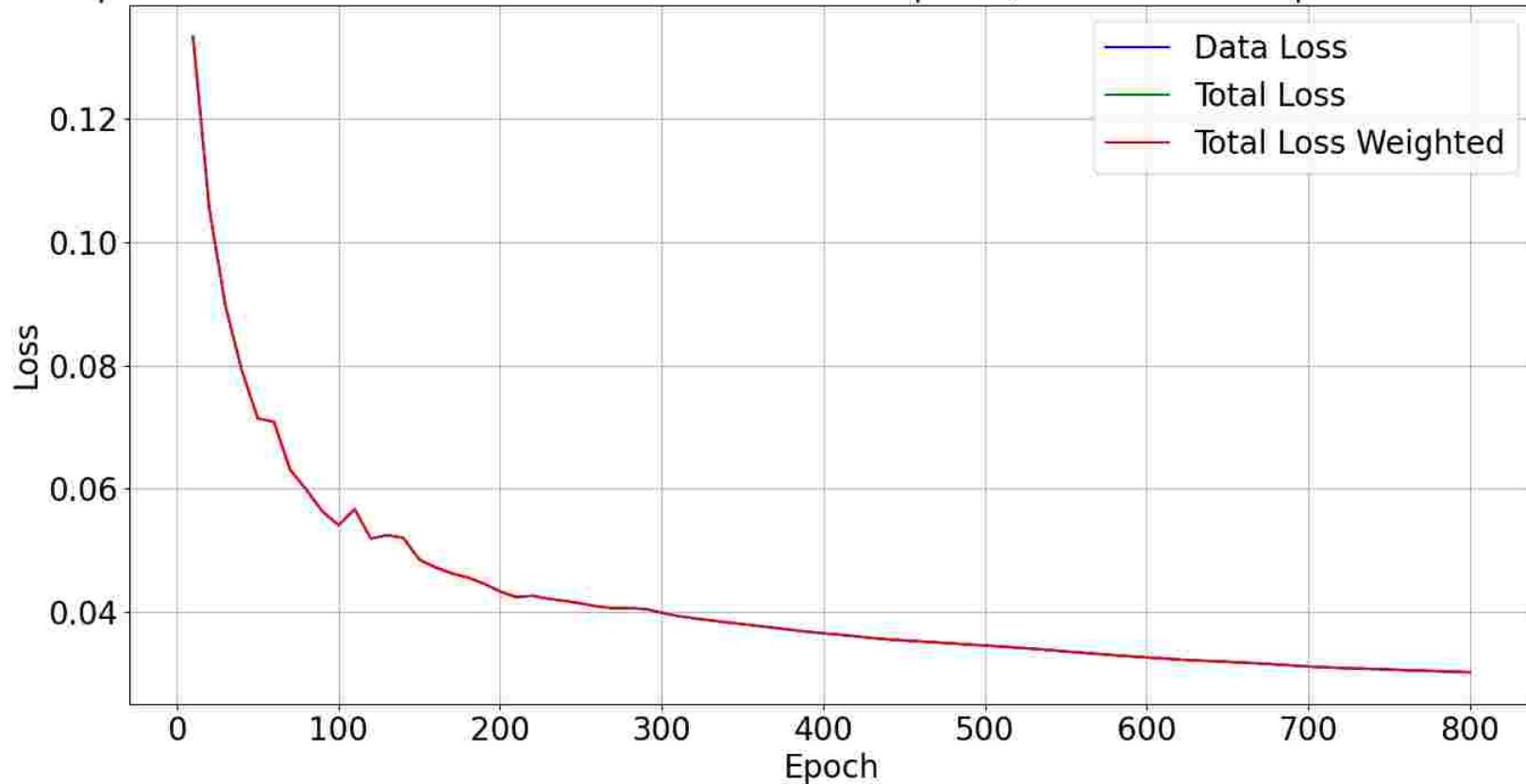
For this run, we will only have input parameters to be [X, Y, Z, $\cos(\theta)$, $\sin(\theta)$] and the output parameters will be [U, V, W]

Reduce Dataset -> x,y = [-2520,2520], z = [0,1000] -> x,y = [-504,504], z = [0,300]

Total Number of Data Points → 2.077241E6 points per wind angle * (5 inputs + 3 outputs) * (12 training wind angles) ~ 1.99E8 (~2.49E8 if we include Pressure and TurbVisc)

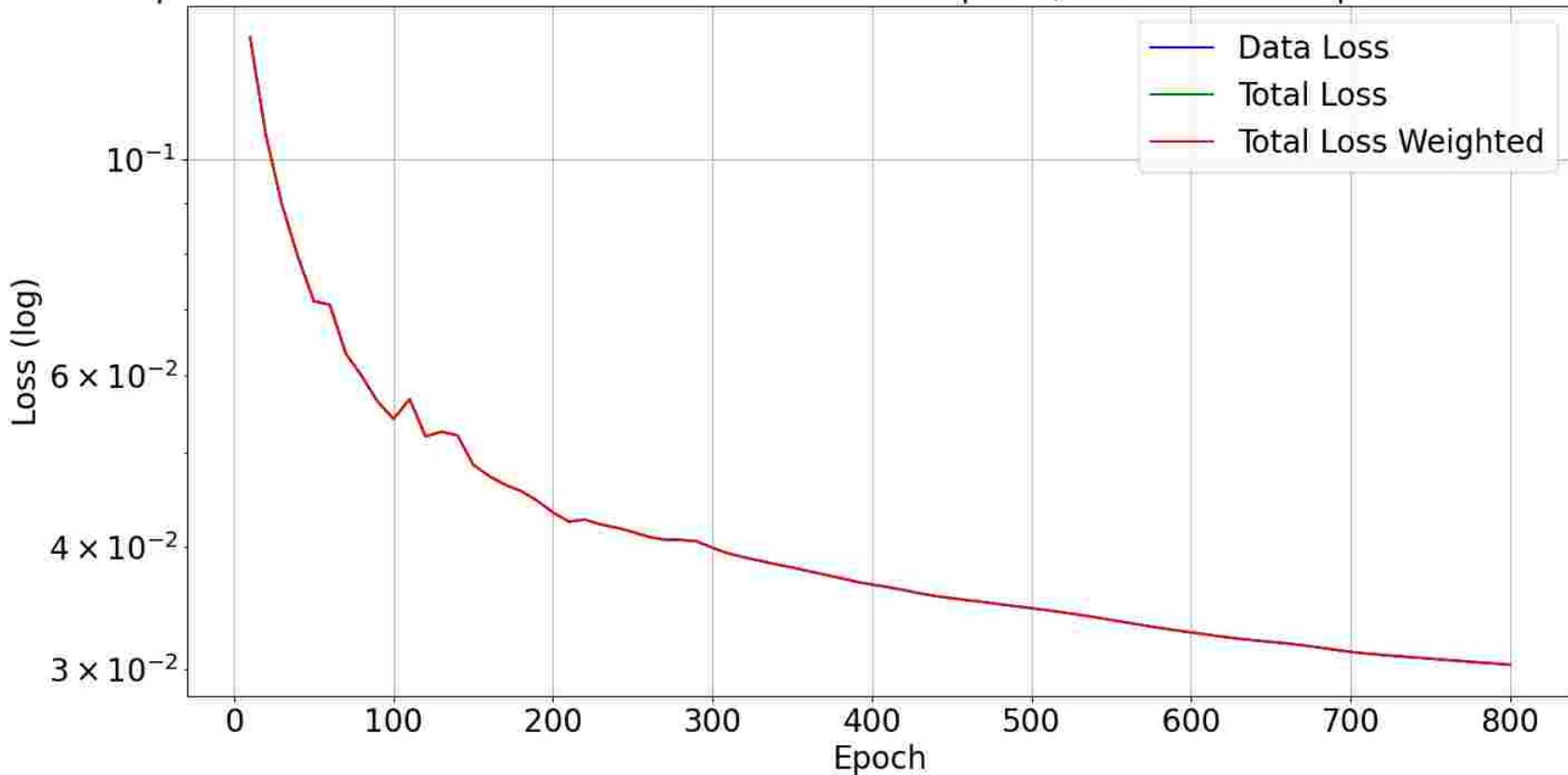
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Threshold = SMA 1E-5 (800 Epochs, not completed), GPU Laptop
Logging Plots (Training)

Epoch vs Loss - Time Taken = 164.98 hours for 800 Epochs; Time Taken Per Epoch = 0.21 hours

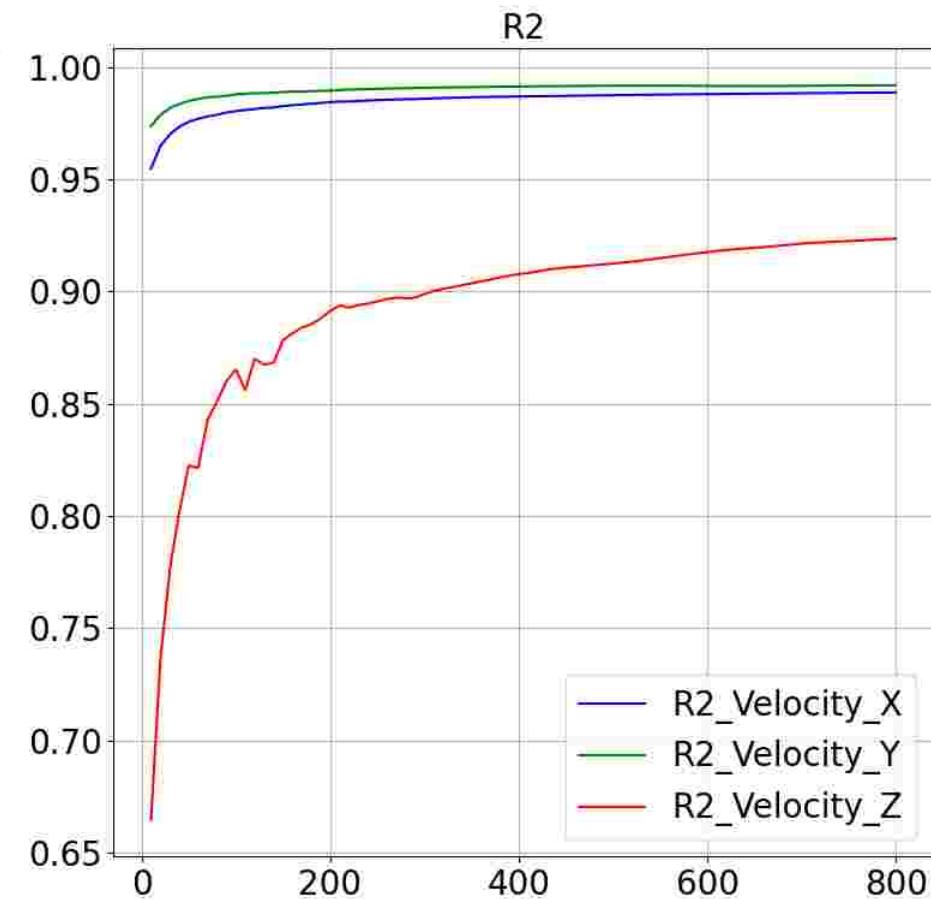
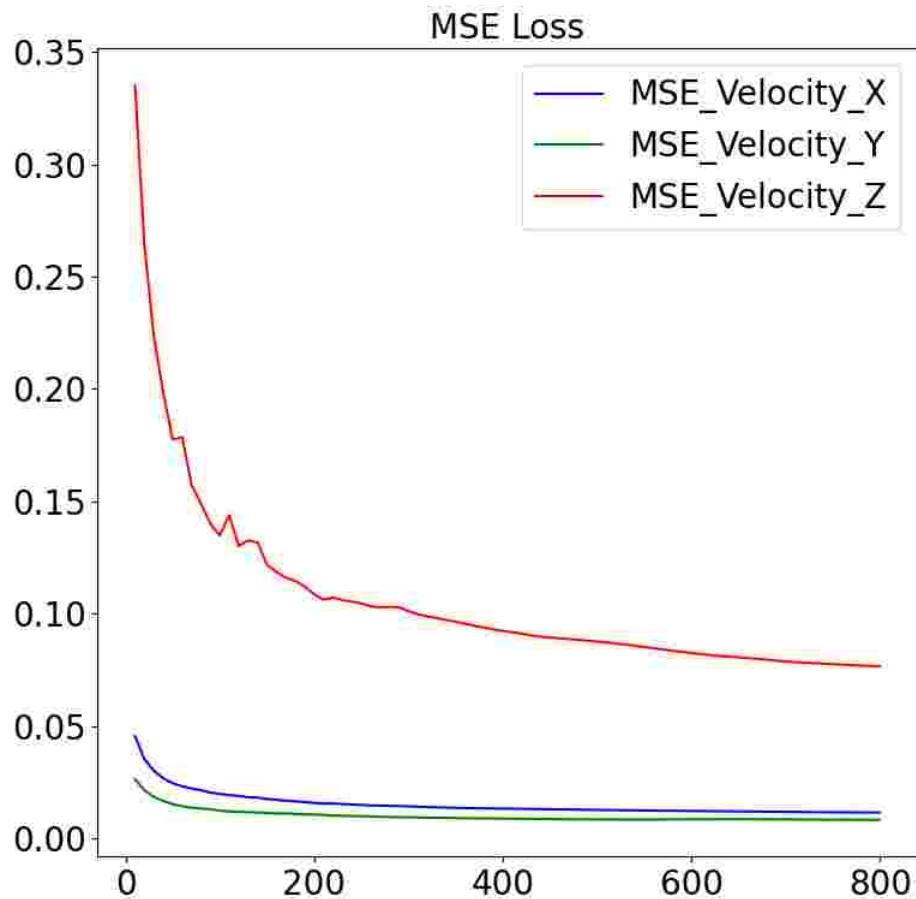


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (800 Epochs, not completed), GPU Laptop
Logging Plots (Training)

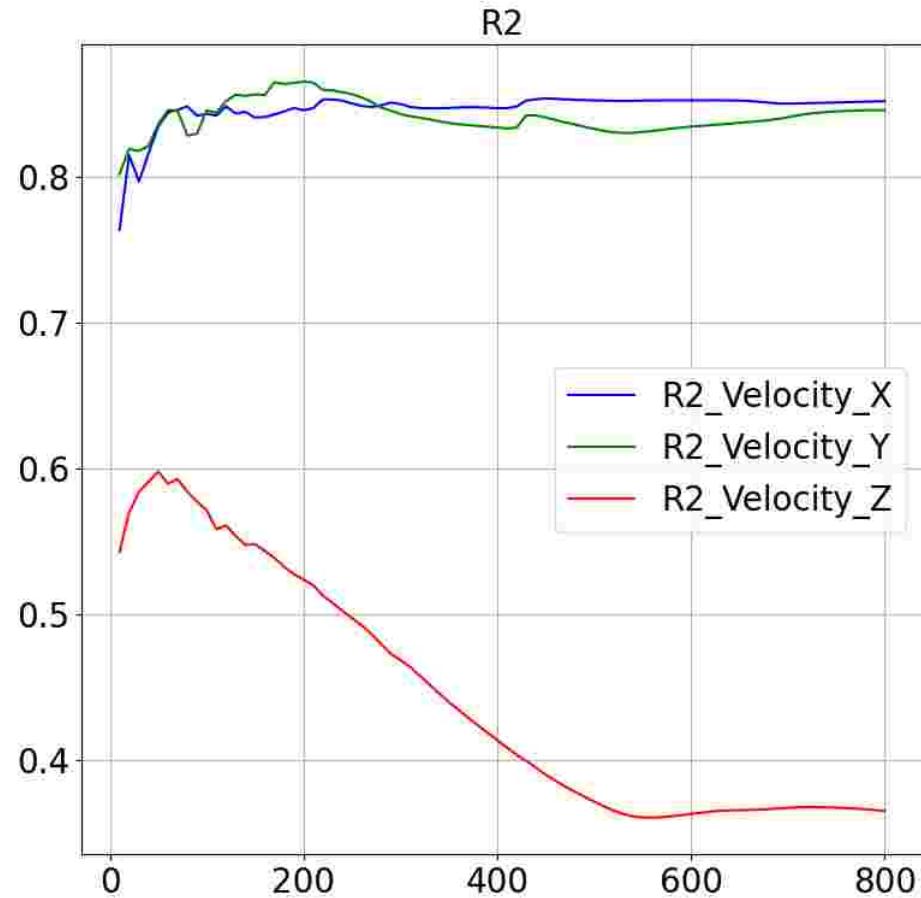
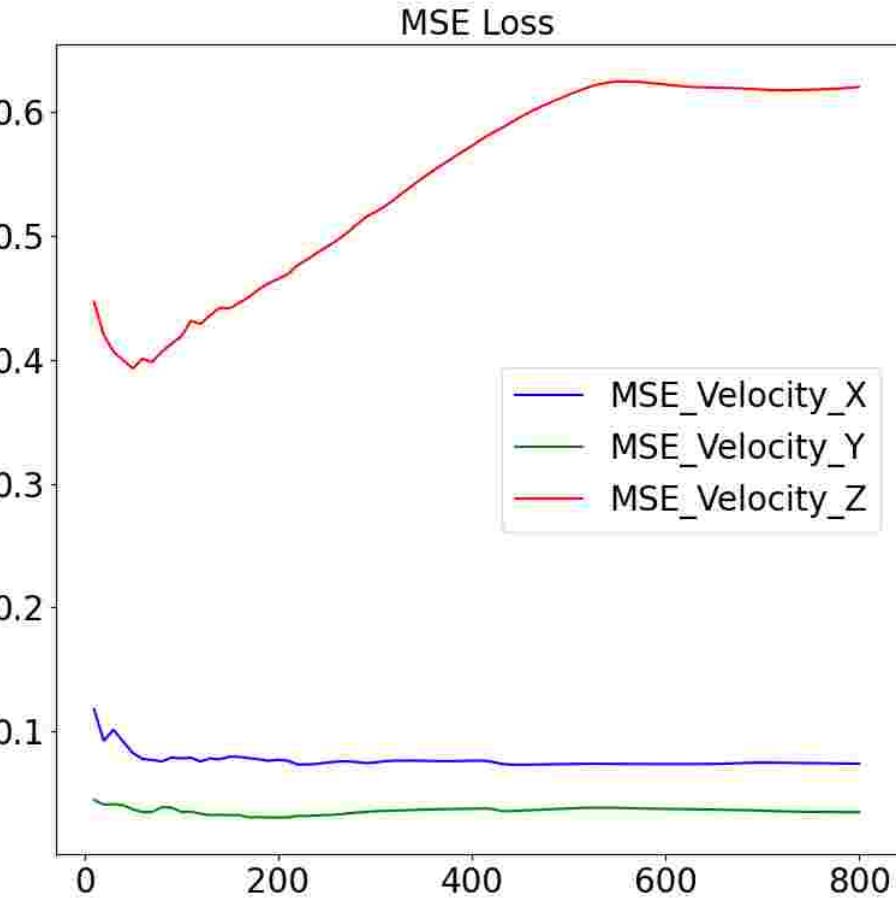
Epoch vs Loss - Time Taken = 164.98 hours for 800 Epochs; Time Taken Per Epoch = 0.21 hours



Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (800 Epochs, not completed), GPU Laptop
Logging Plots (Testing)

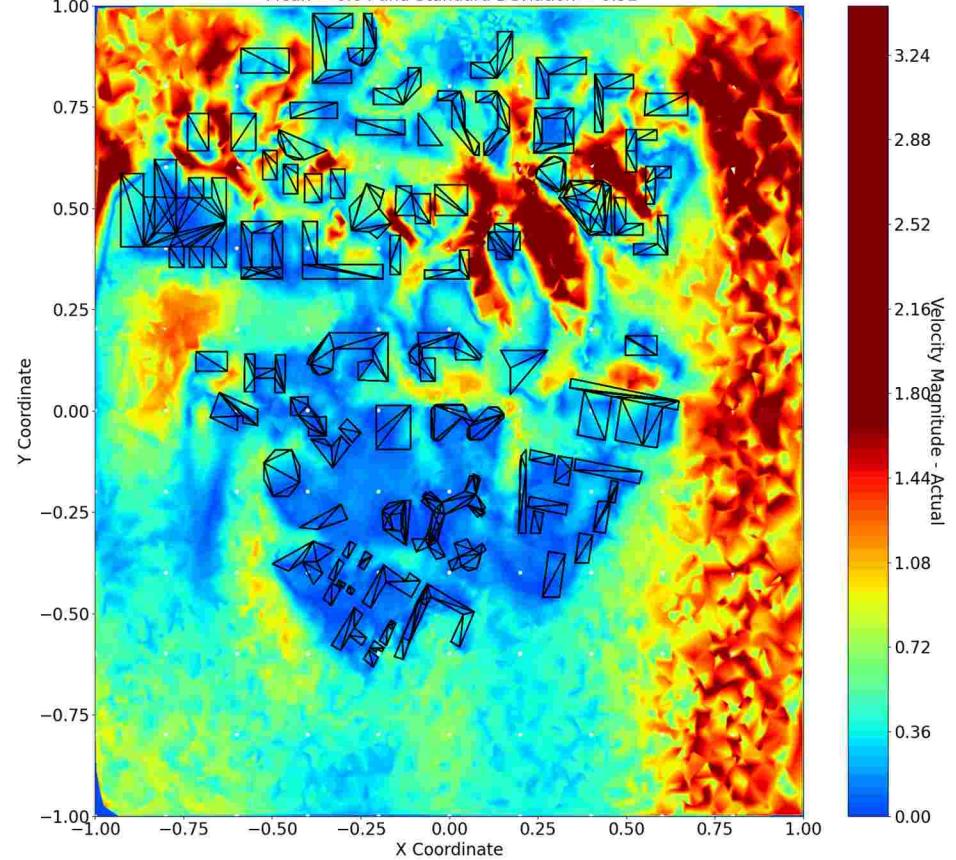


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (800 Epochs, not completed), GPU Laptop
Logging Plots (Predicting 135)

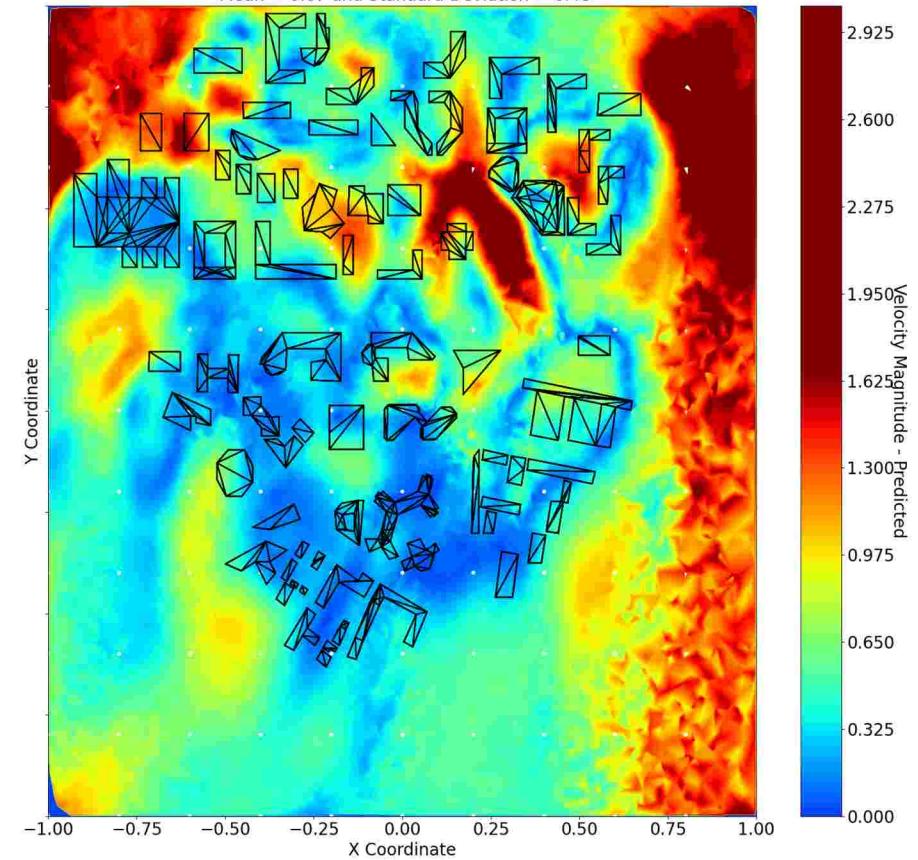


Comparison of Actual vs. Predicted values with Wind Angle = 0 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.02 +/- 0.02
Mean = 0.64 and Standard Deviation = 0.51

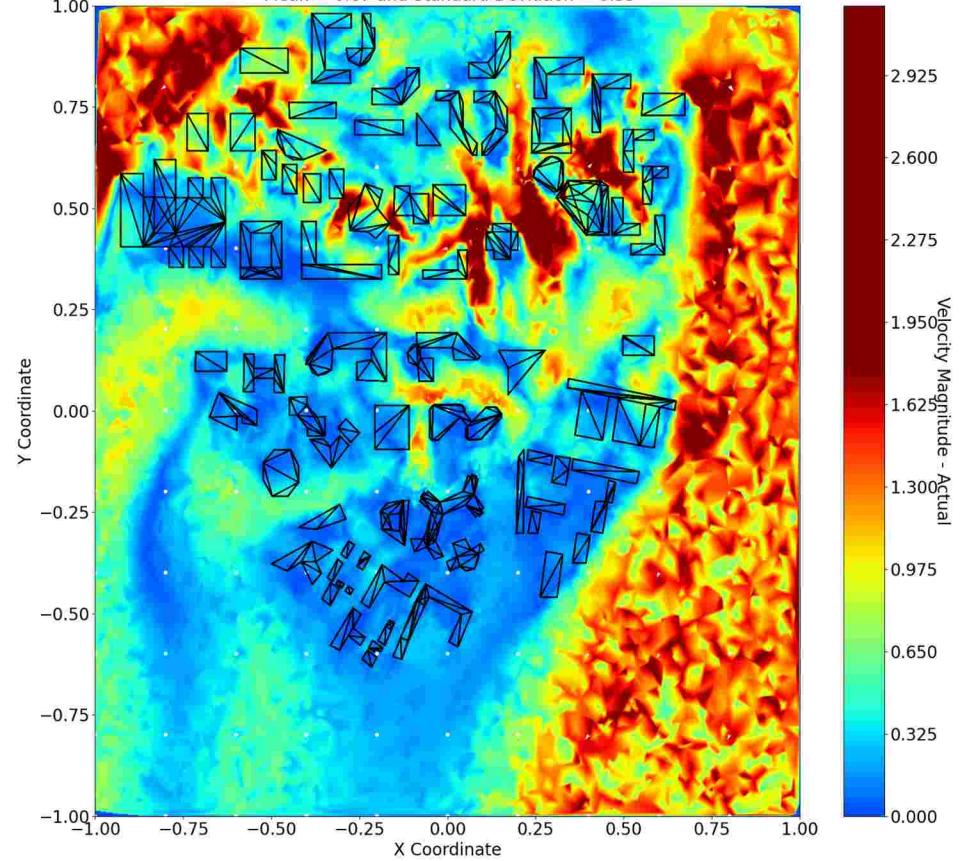


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.02 +/- 0.02
Mean = 0.67 and Standard Deviation = 0.48

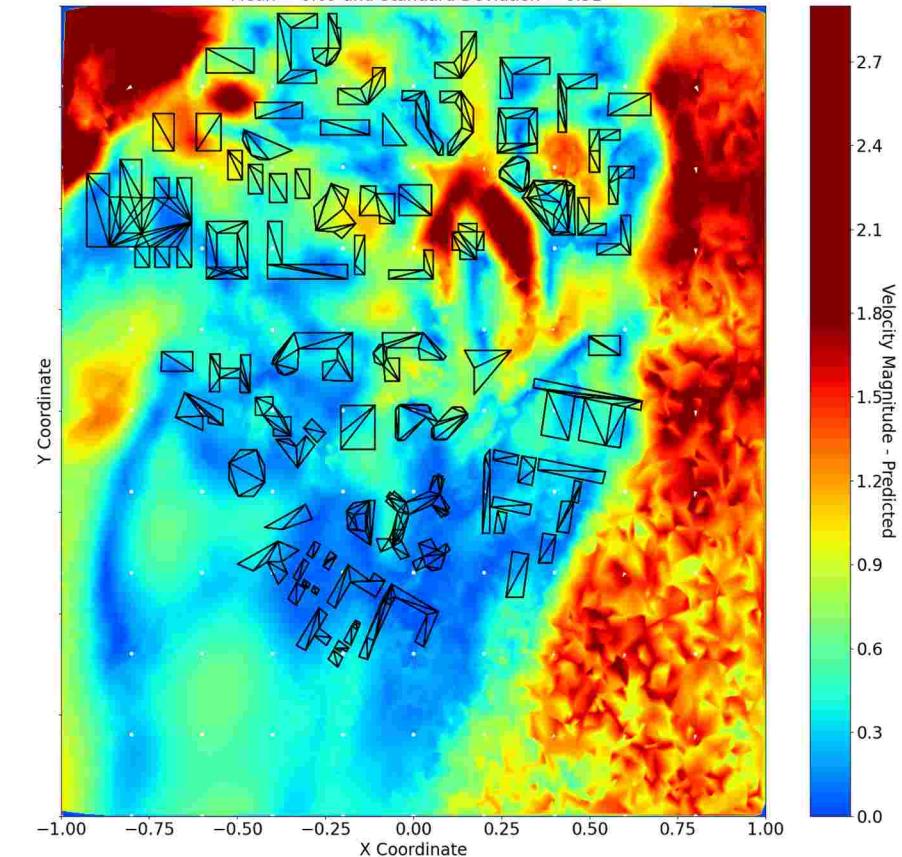


Comparison of Actual vs. Predicted values with Wind Angle = 15 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.02 +/- 0.02
Mean = 0.67 and Standard Deviation = 0.55

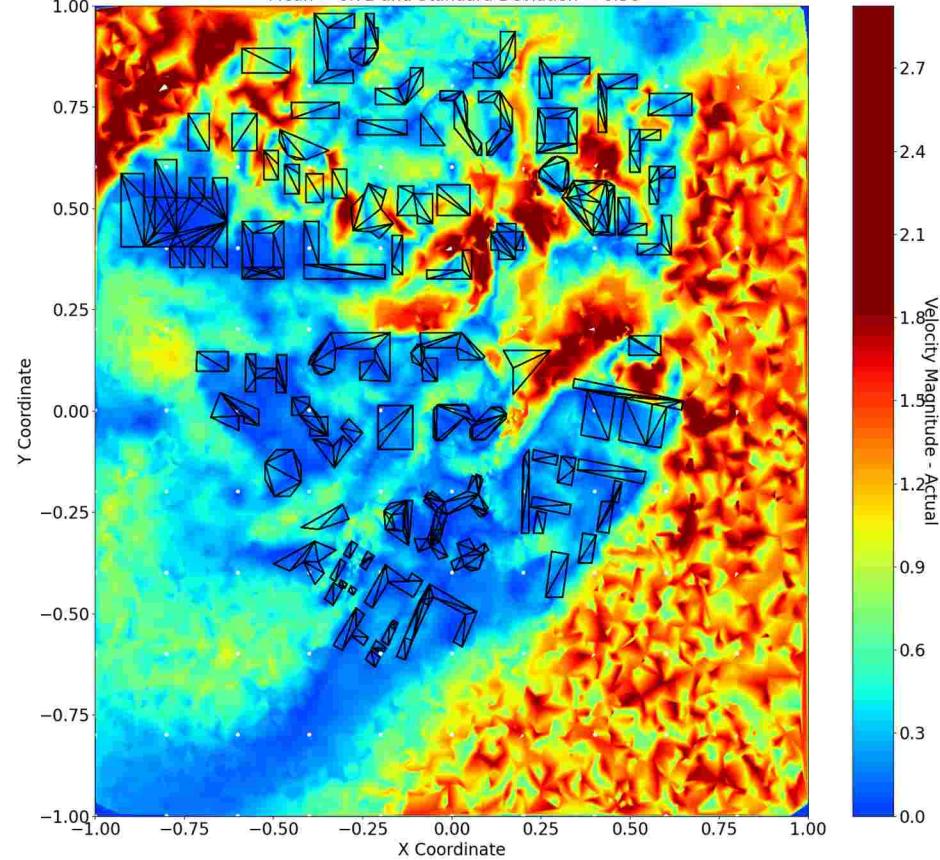


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.02 +/- 0.02
Mean = 0.69 and Standard Deviation = 0.51

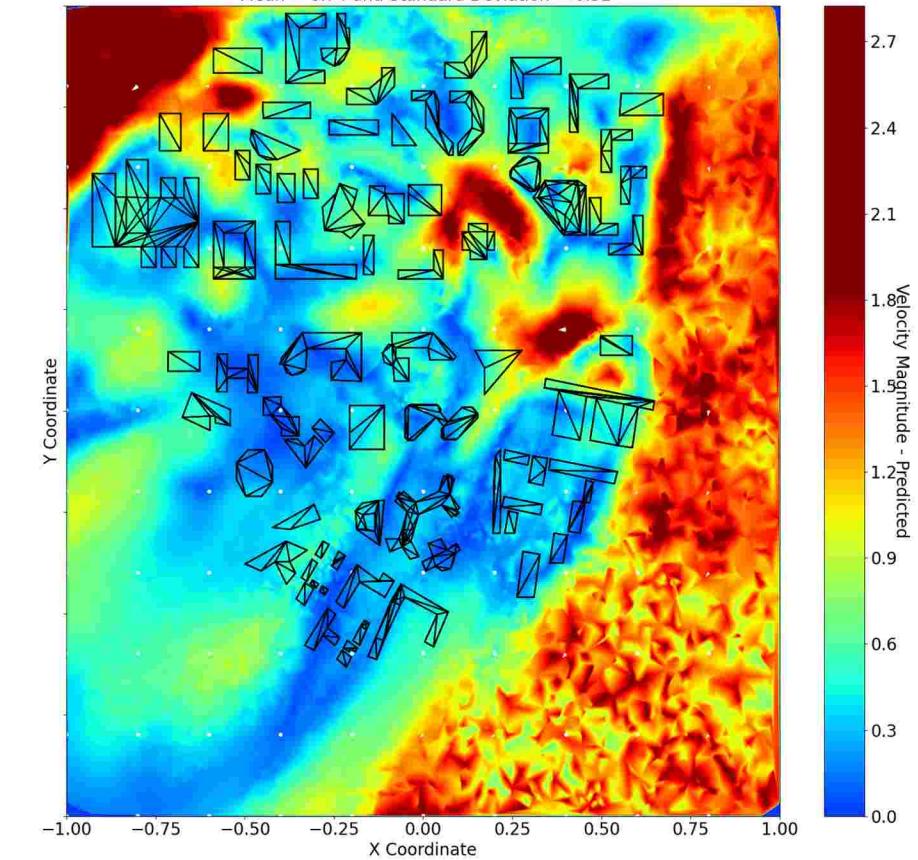


Comparison of Actual vs. Predicted values with Wind Angle = 30 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.02 +/- 0.02
Mean = 0.72 and Standard Deviation = 0.56

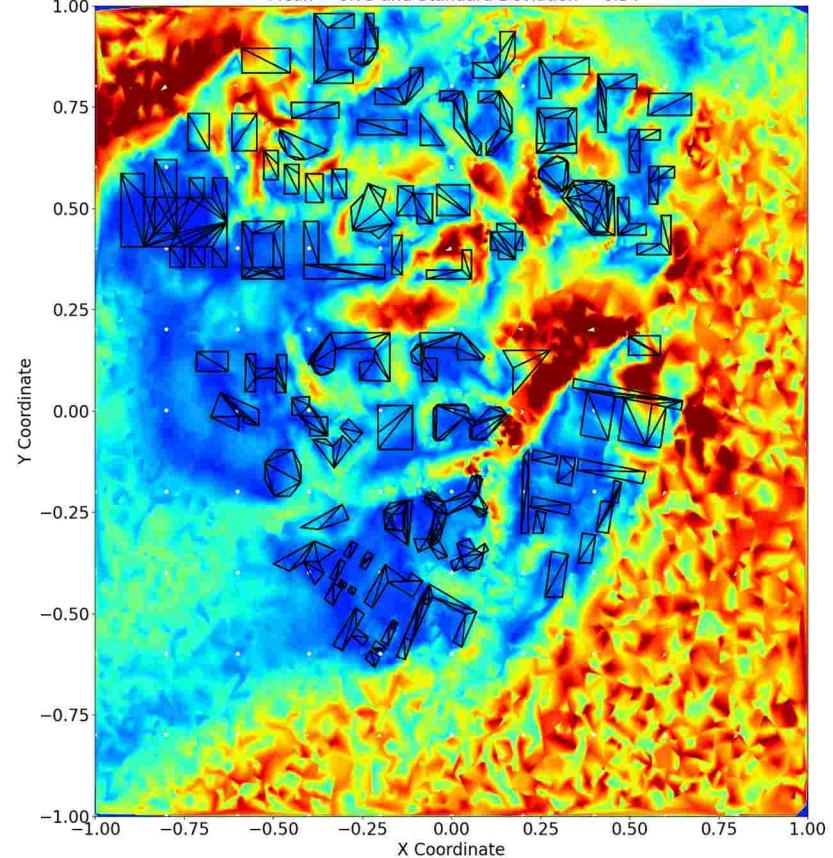


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.02 +/- 0.02
Mean = 0.74 and Standard Deviation = 0.52

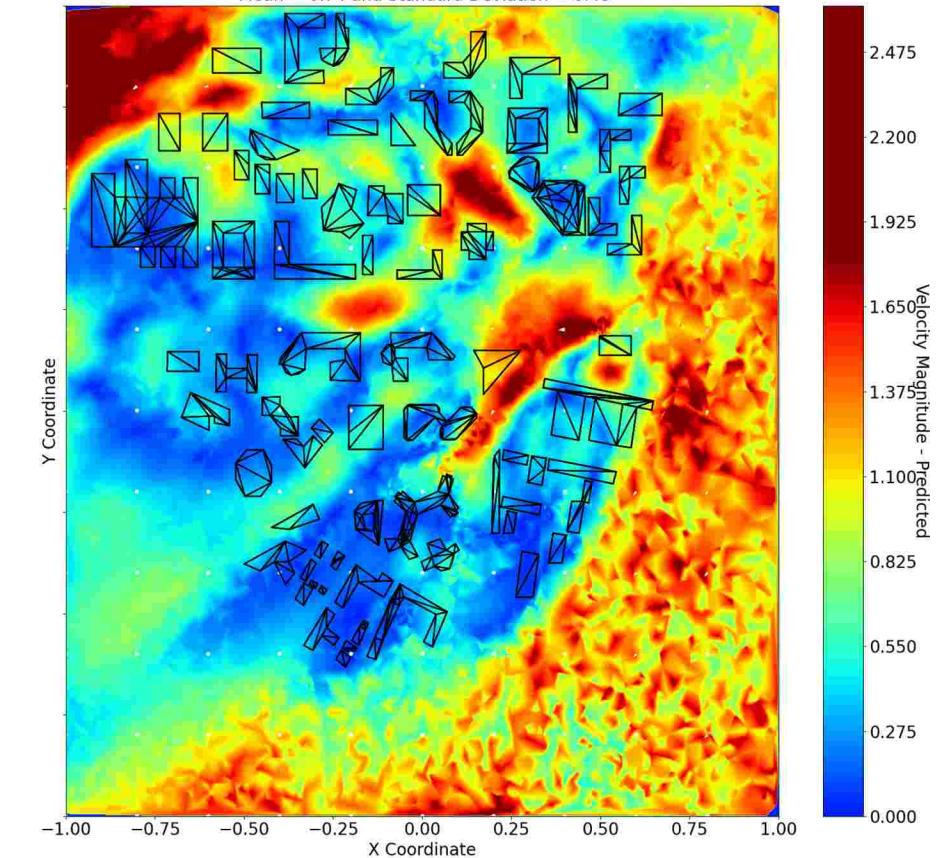


Comparison of Actual vs. Predicted values with Wind Angle = 45 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.02 +/- 0.02
Mean = 0.75 and Standard Deviation = 0.54

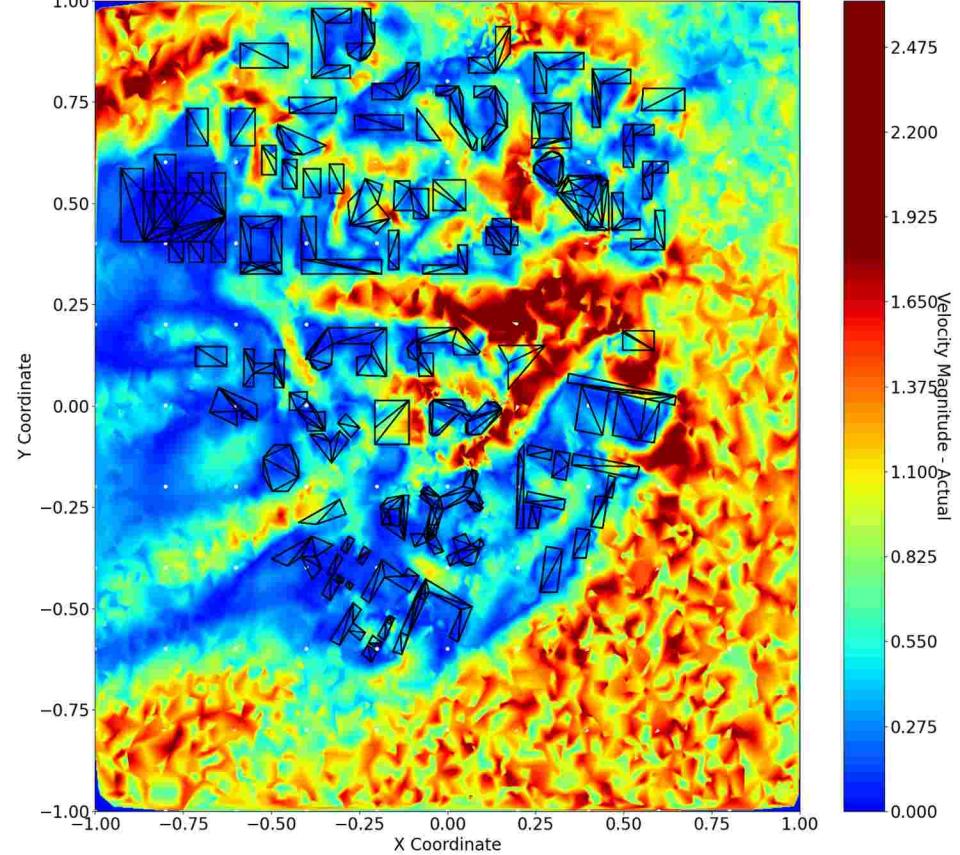


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.02 +/- 0.02
Mean = 0.74 and Standard Deviation = 0.48

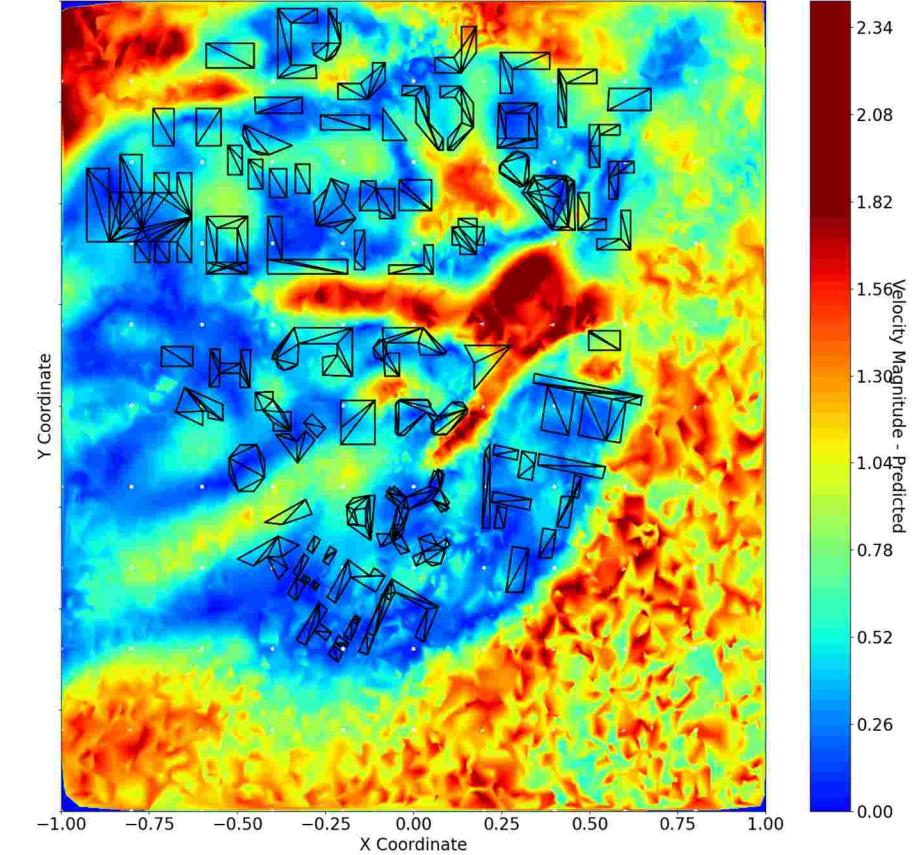


Comparison of Actual vs. Predicted values with Wind Angle = 60 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.02 +/- 0.02
Mean = 0.77 and Standard Deviation = 0.52

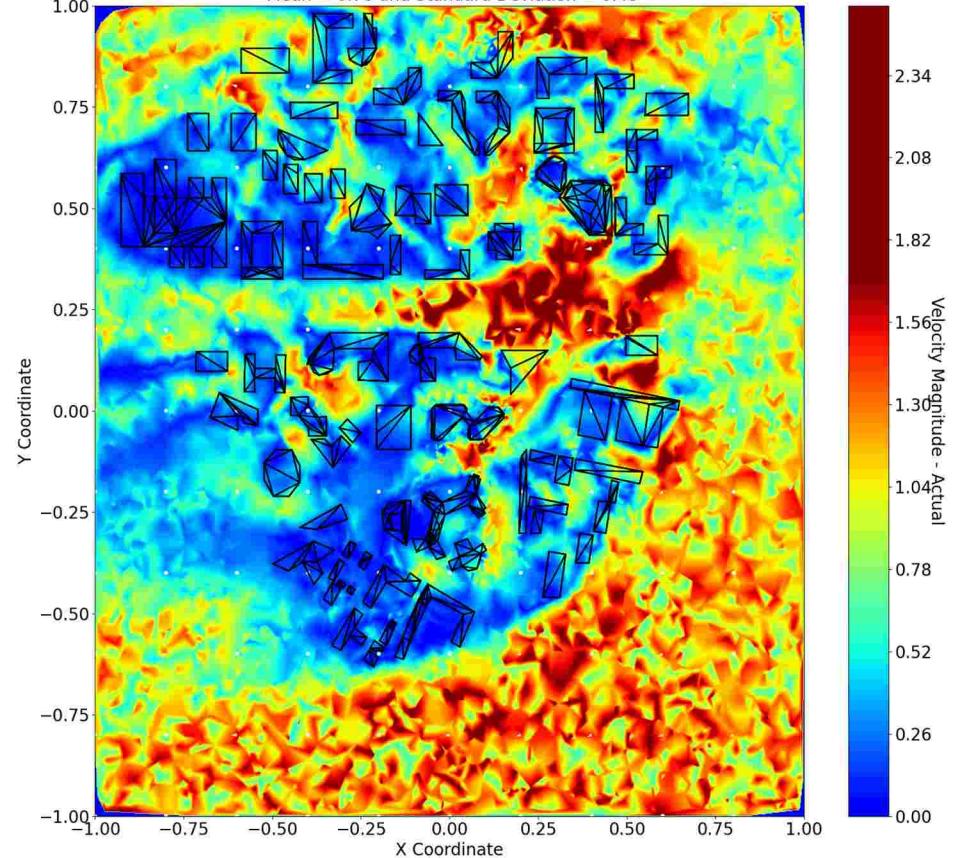


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.02 +/- 0.02
Mean = 0.75 and Standard Deviation = 0.45

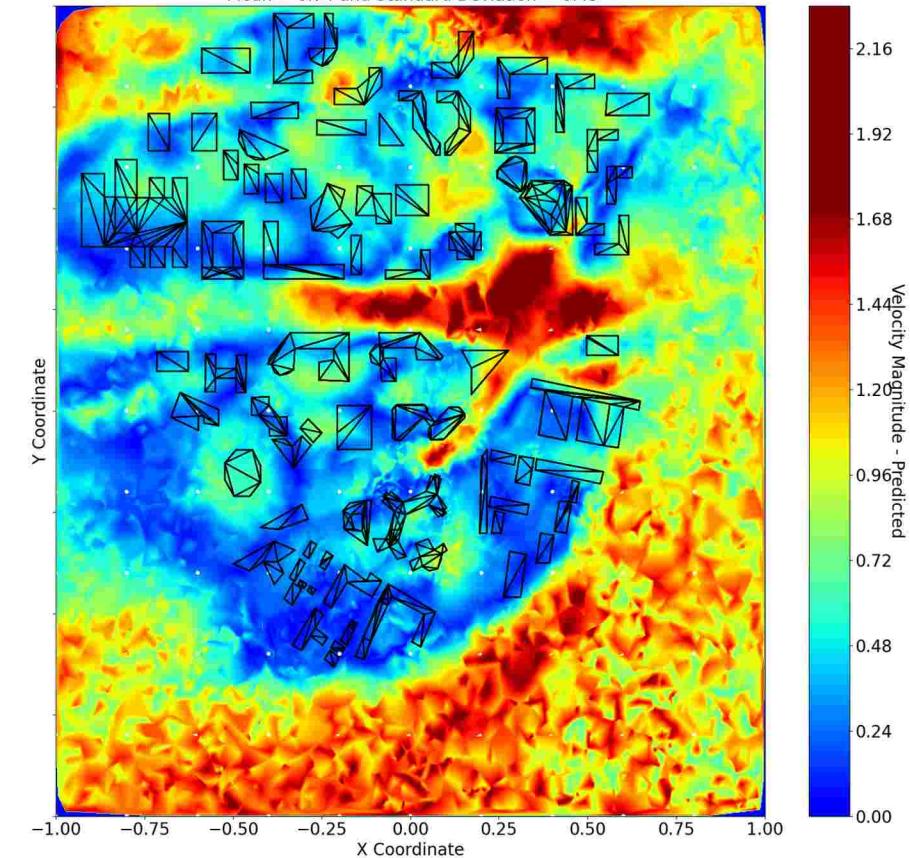


Comparison of Actual vs. Predicted values with Wind Angle = 75 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.02 +/- 0.02
Mean = 0.76 and Standard Deviation = 0.48

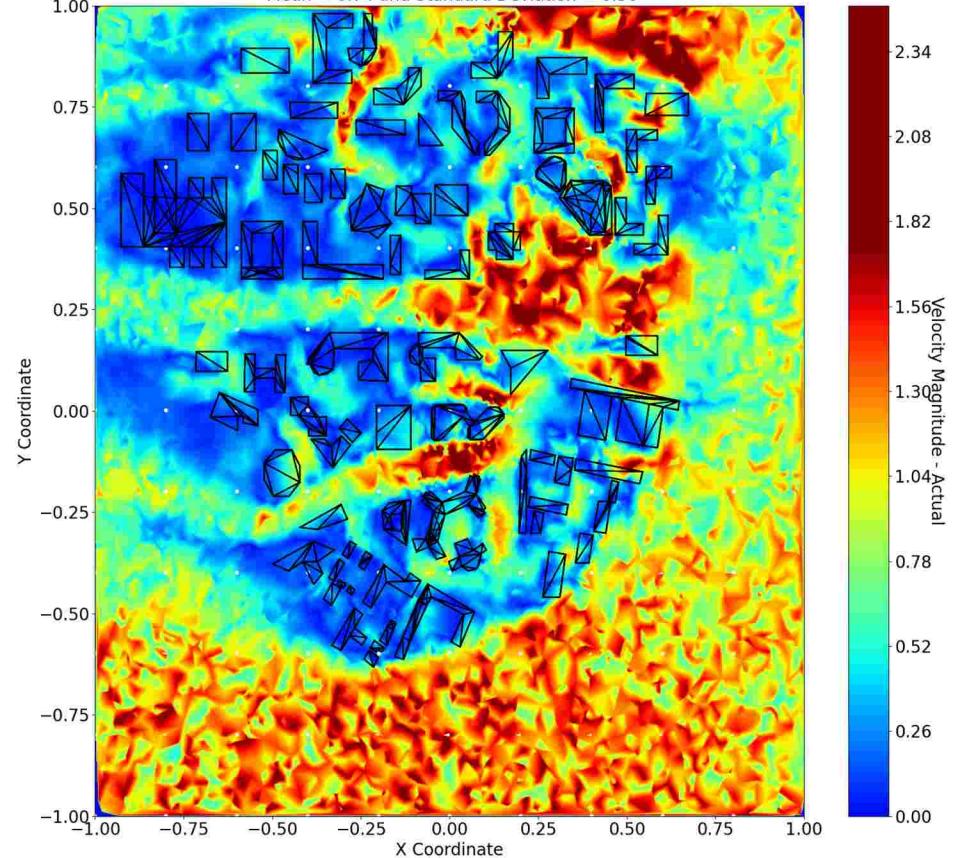


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.02 +/- 0.02
Mean = 0.74 and Standard Deviation = 0.43

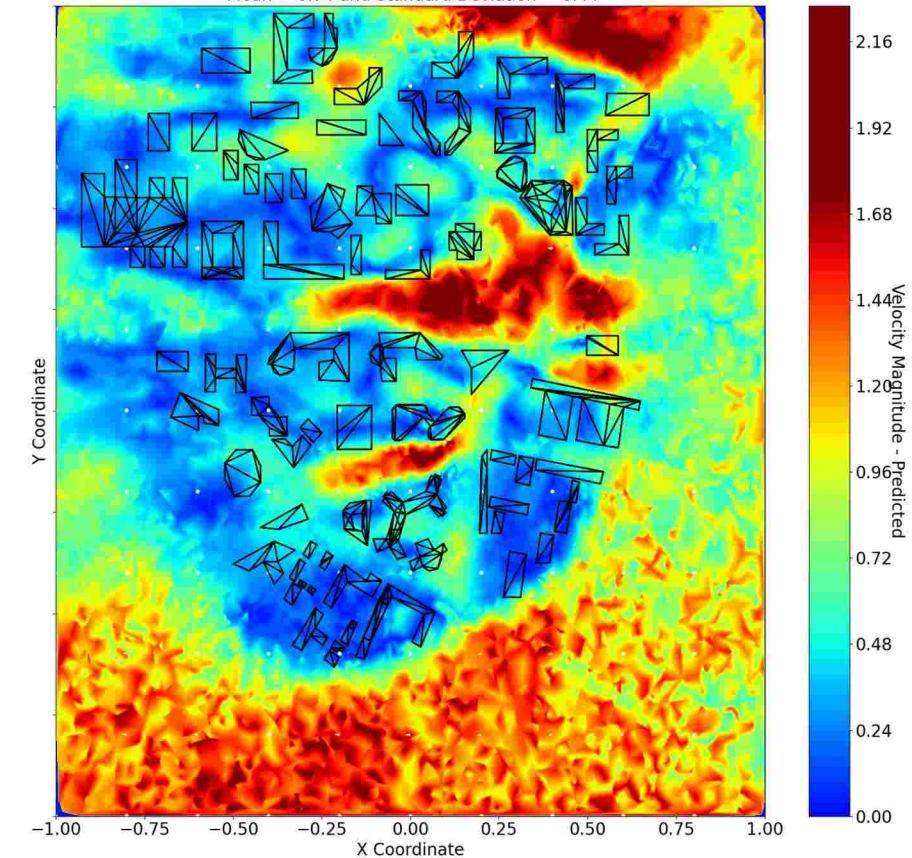


Comparison of Actual vs. Predicted values with Wind Angle = 90 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.02 +/- 0.02
Mean = 0.74 and Standard Deviation = 0.50

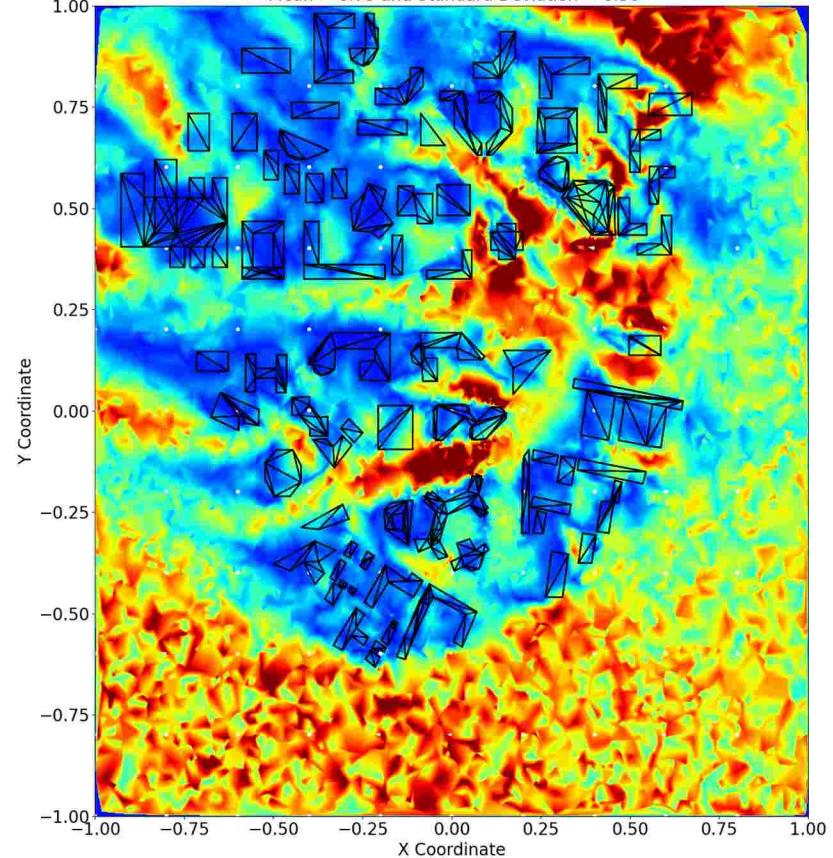


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.02 +/- 0.02
Mean = 0.74 and Standard Deviation = 0.44

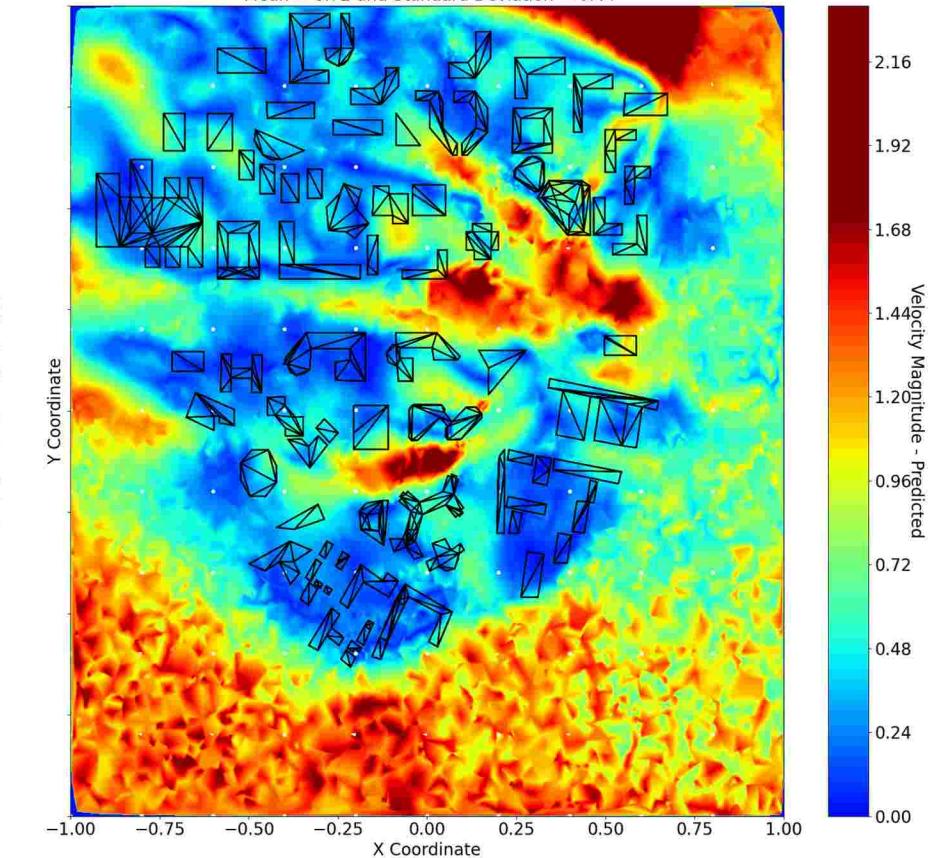


Comparison of Actual vs. Predicted values with Wind Angle = 105 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.02 +/- 0.02
Mean = 0.73 and Standard Deviation = 0.50

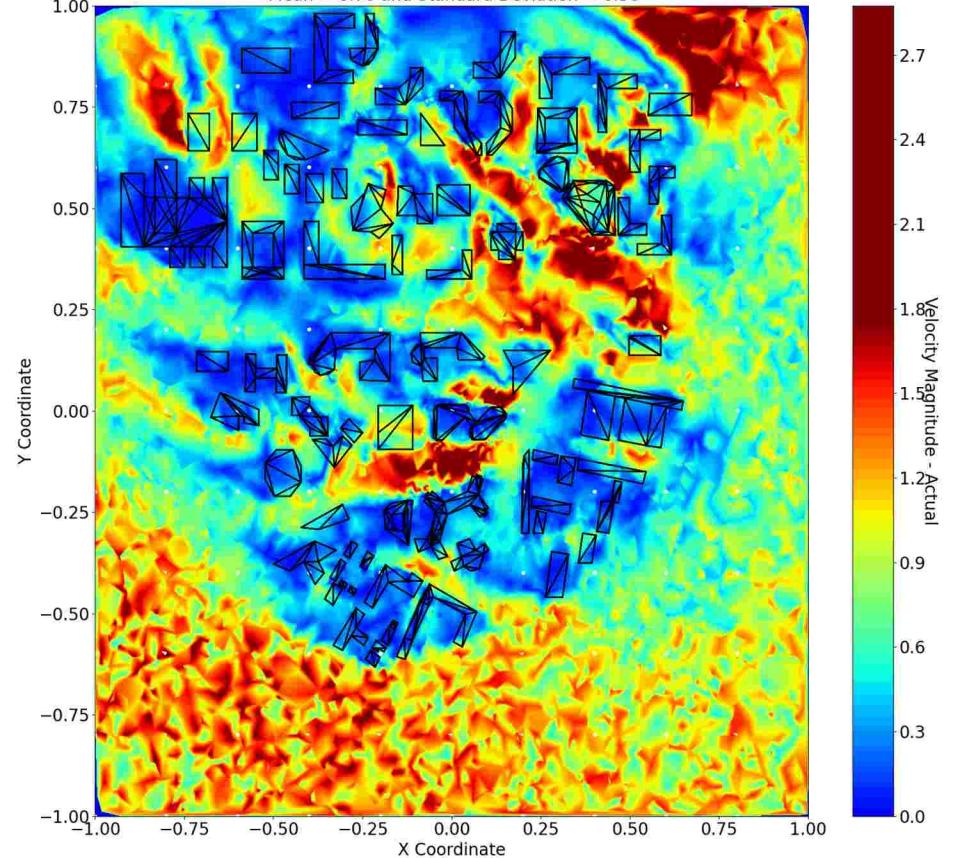


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.02 +/- 0.02
Mean = 0.72 and Standard Deviation = 0.44

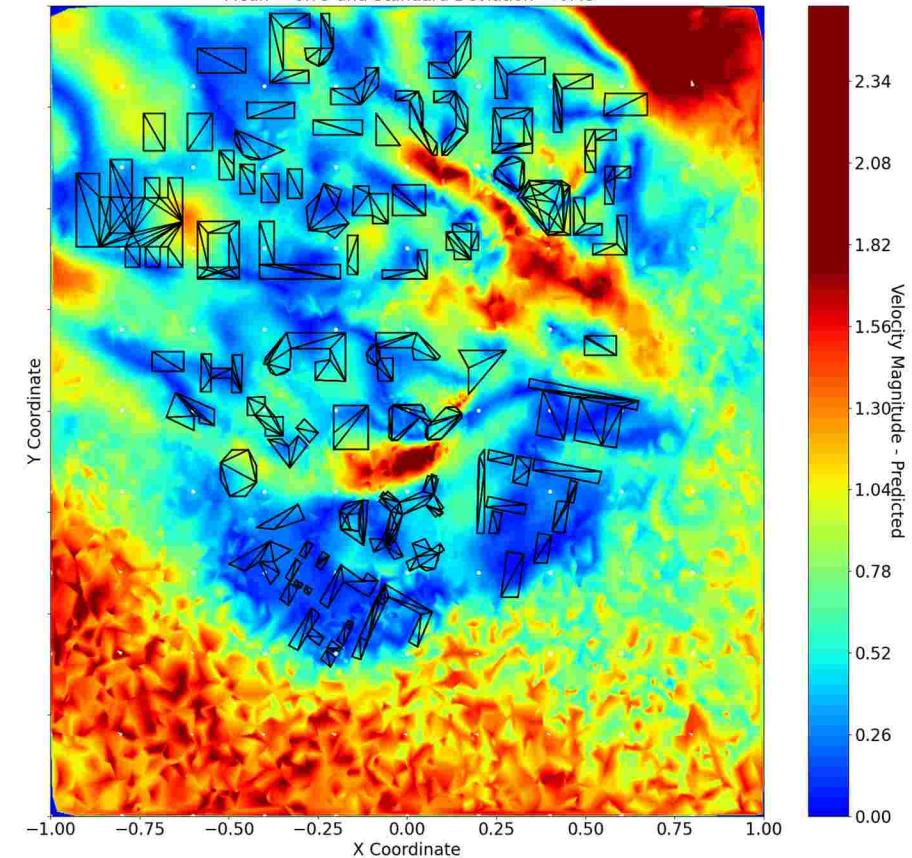


Comparison of Actual vs. Predicted values with Wind Angle = 120 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.02 +/- 0.02
Mean = 0.76 and Standard Deviation = 0.50

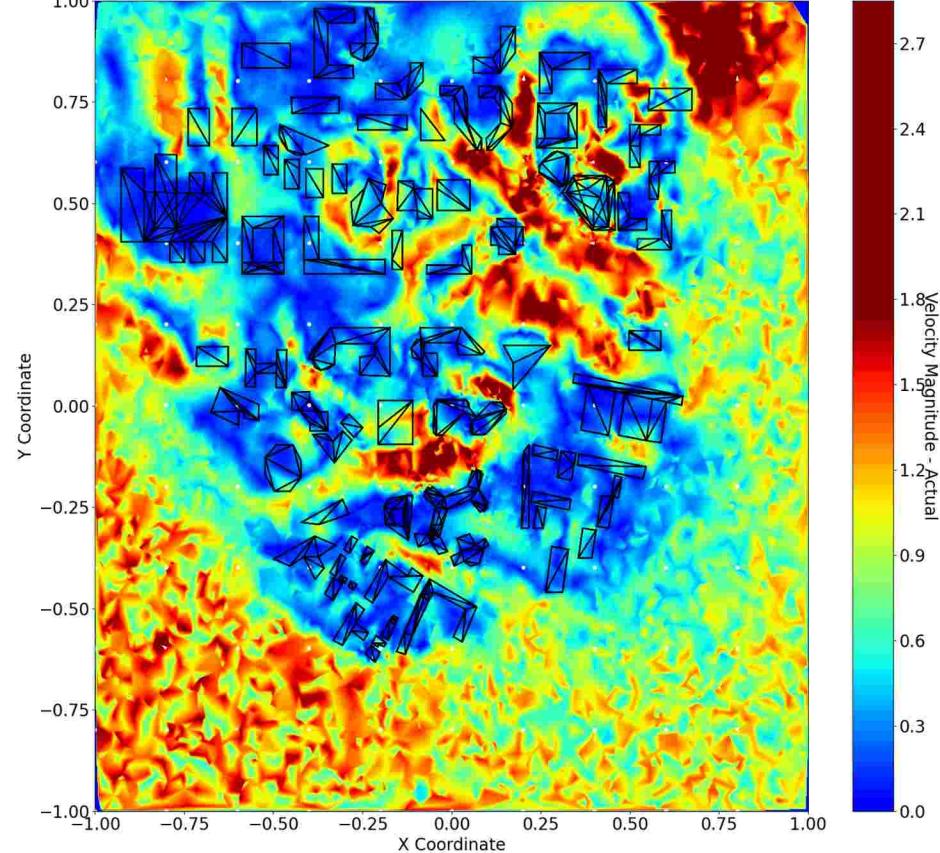


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.02 +/- 0.02
Mean = 0.75 and Standard Deviation = 0.45

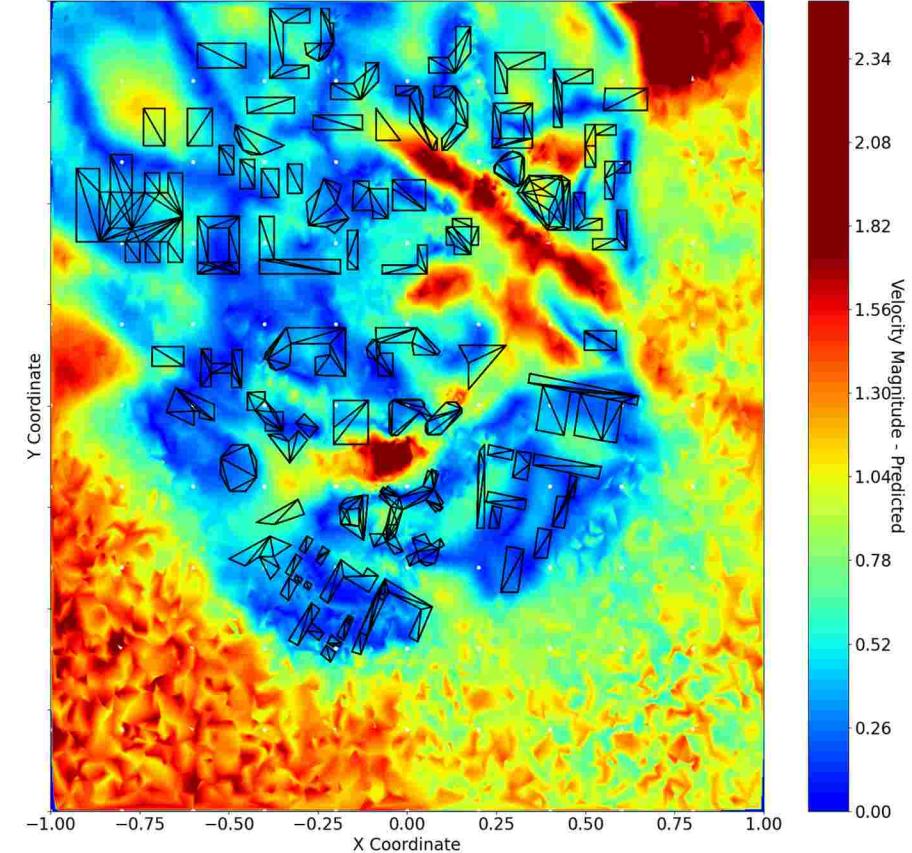


Comparison of Actual vs. Predicted values with Wind Angle = 150 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.02 +/- 0.02
Mean = 0.77 and Standard Deviation = 0.49

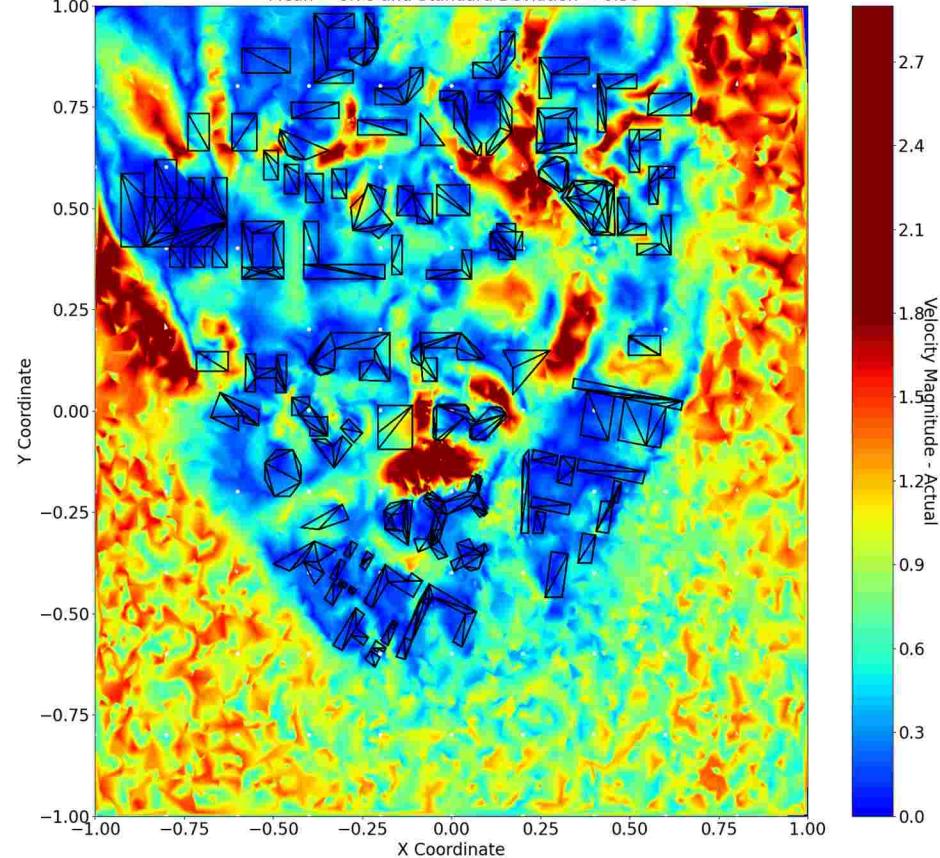


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.02 +/- 0.02
Mean = 0.76 and Standard Deviation = 0.44

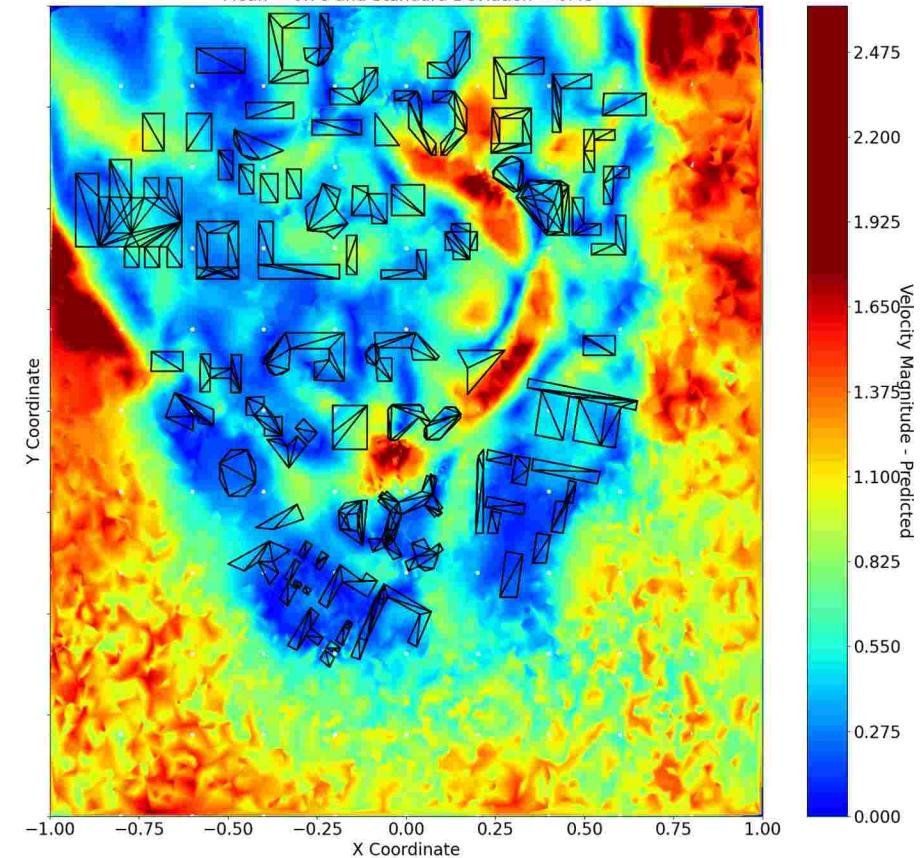


Comparison of Actual vs. Predicted values with Wind Angle = 165 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.02 +/- 0.02
Mean = 0.78 and Standard Deviation = 0.50

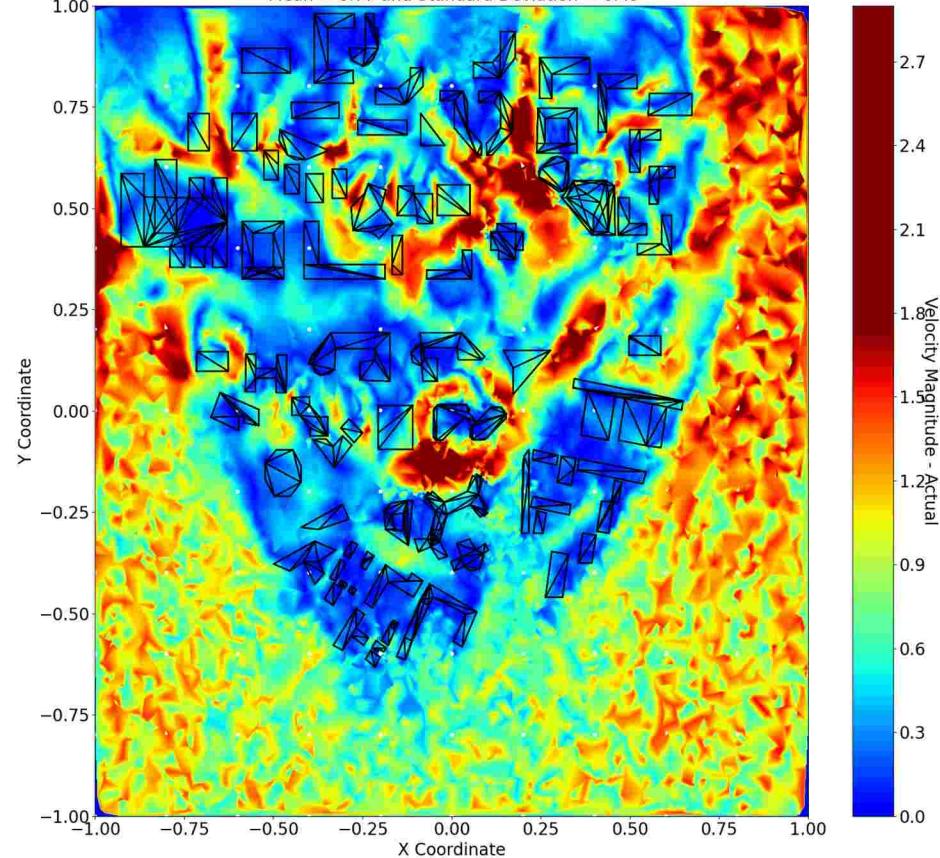


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.02 +/- 0.02
Mean = 0.76 and Standard Deviation = 0.43

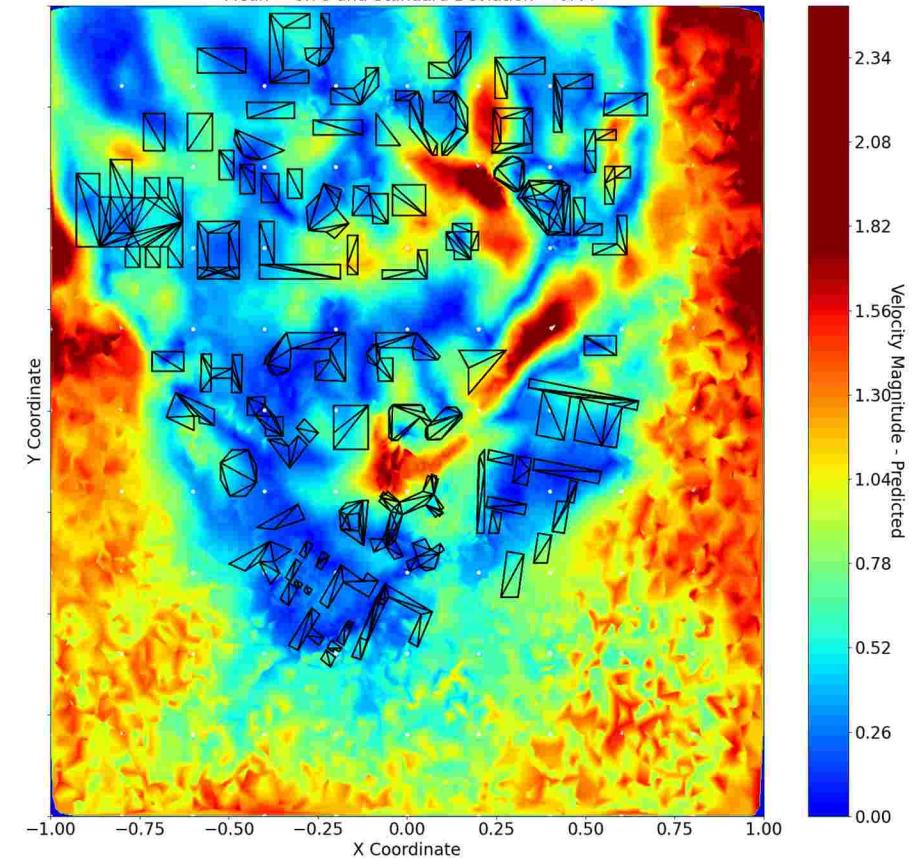


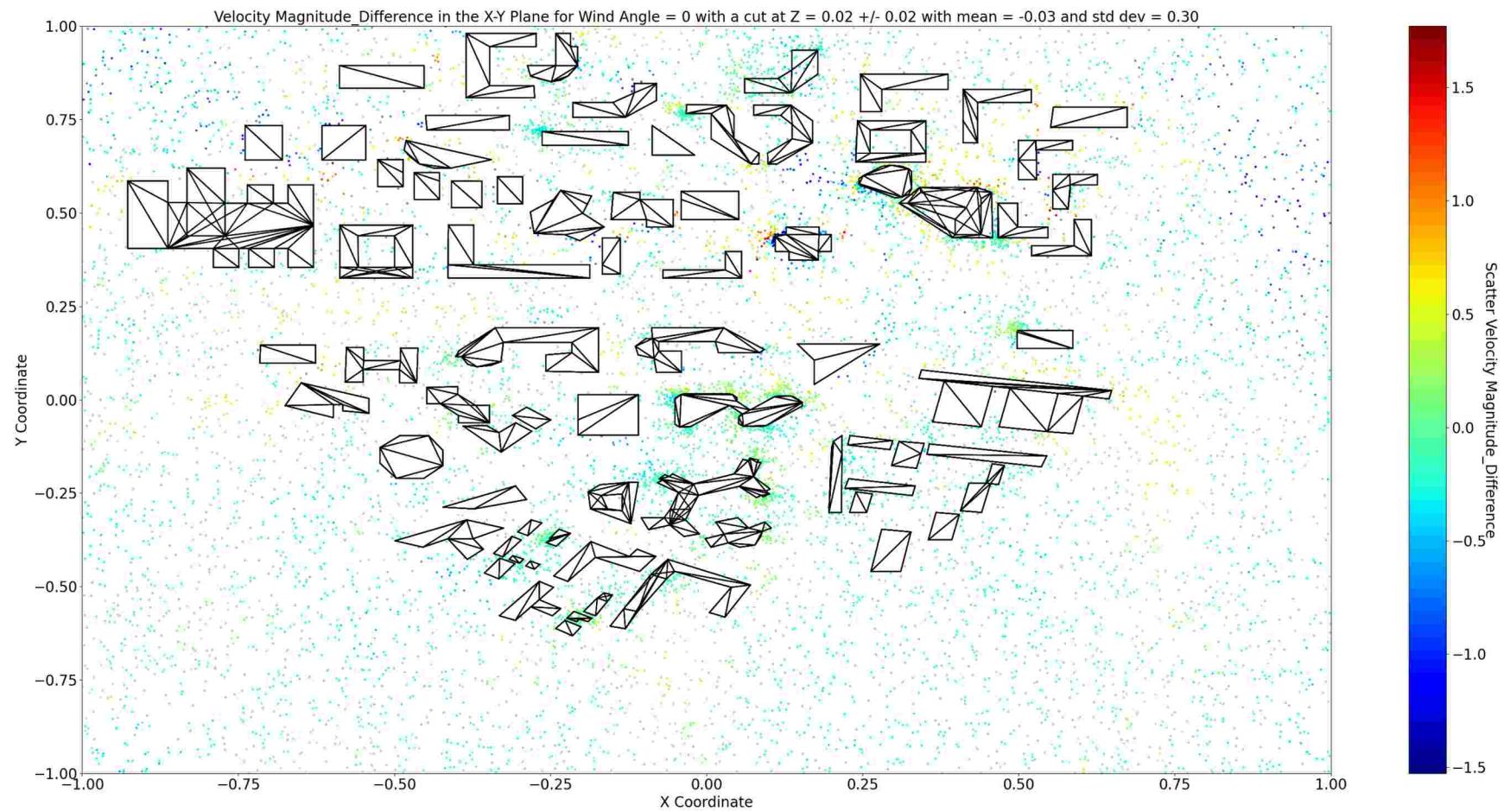
Comparison of Actual vs. Predicted values with Wind Angle = 180 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

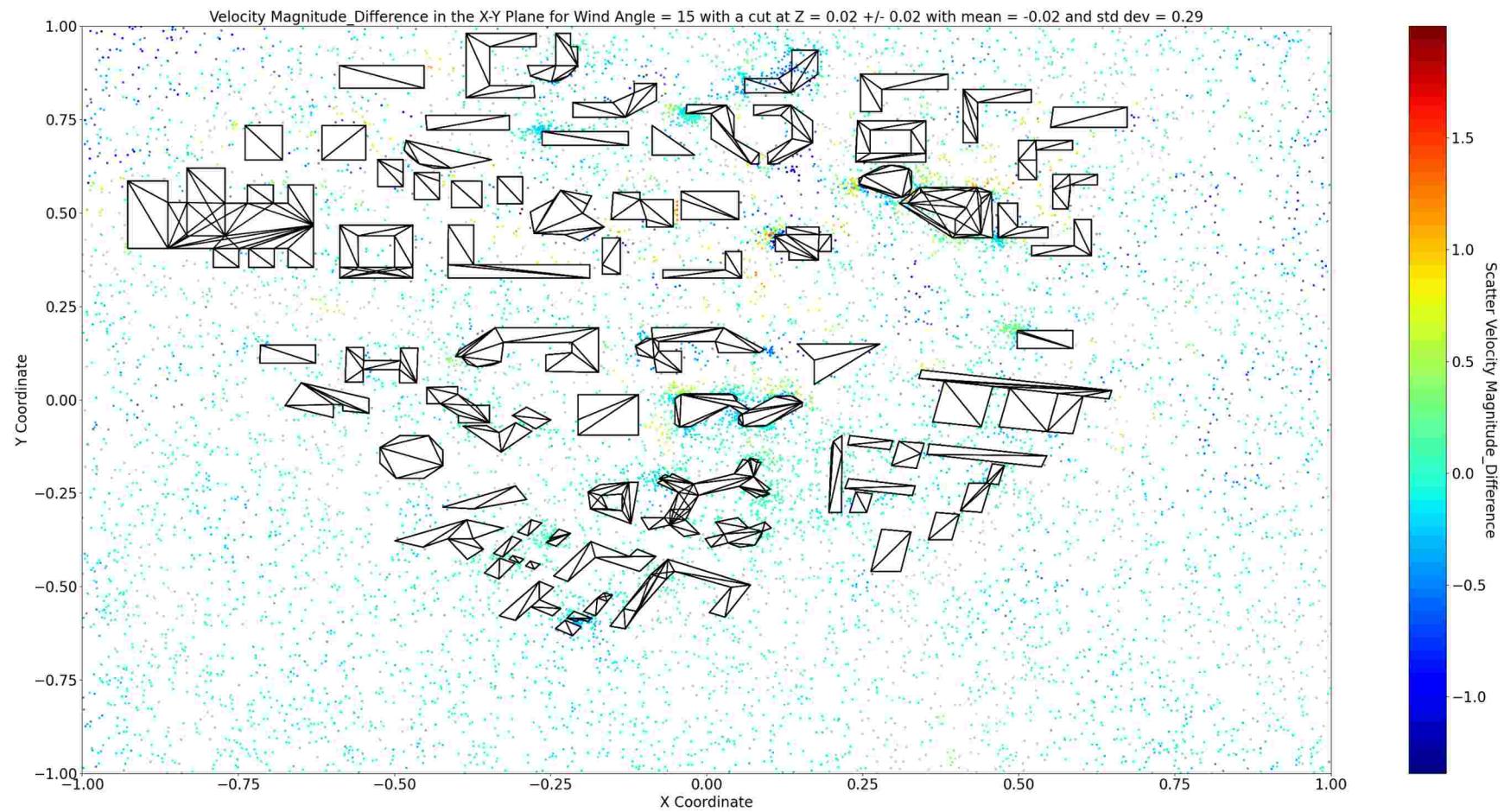
Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.02 +/- 0.02
Mean = 0.77 and Standard Deviation = 0.49

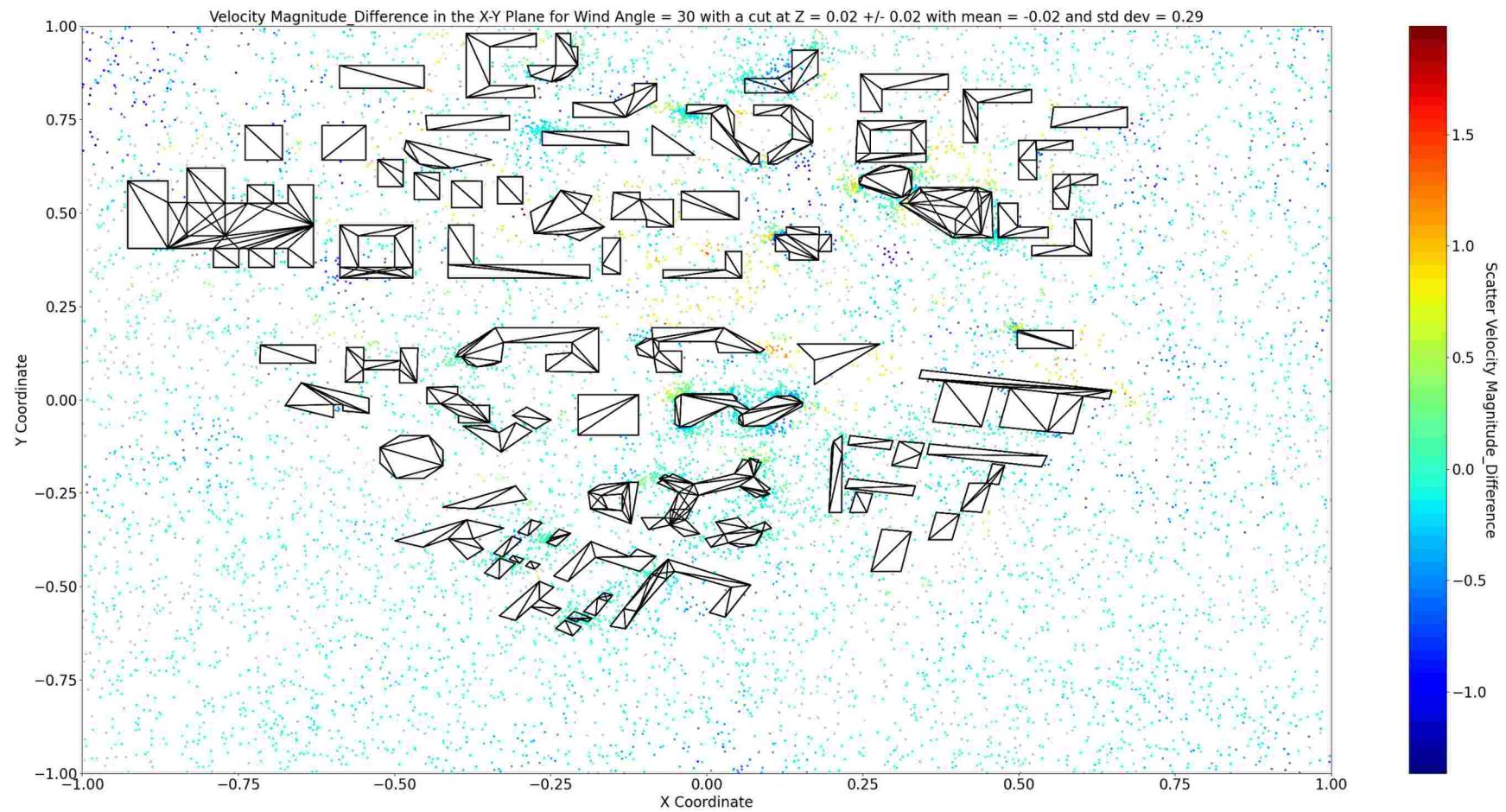


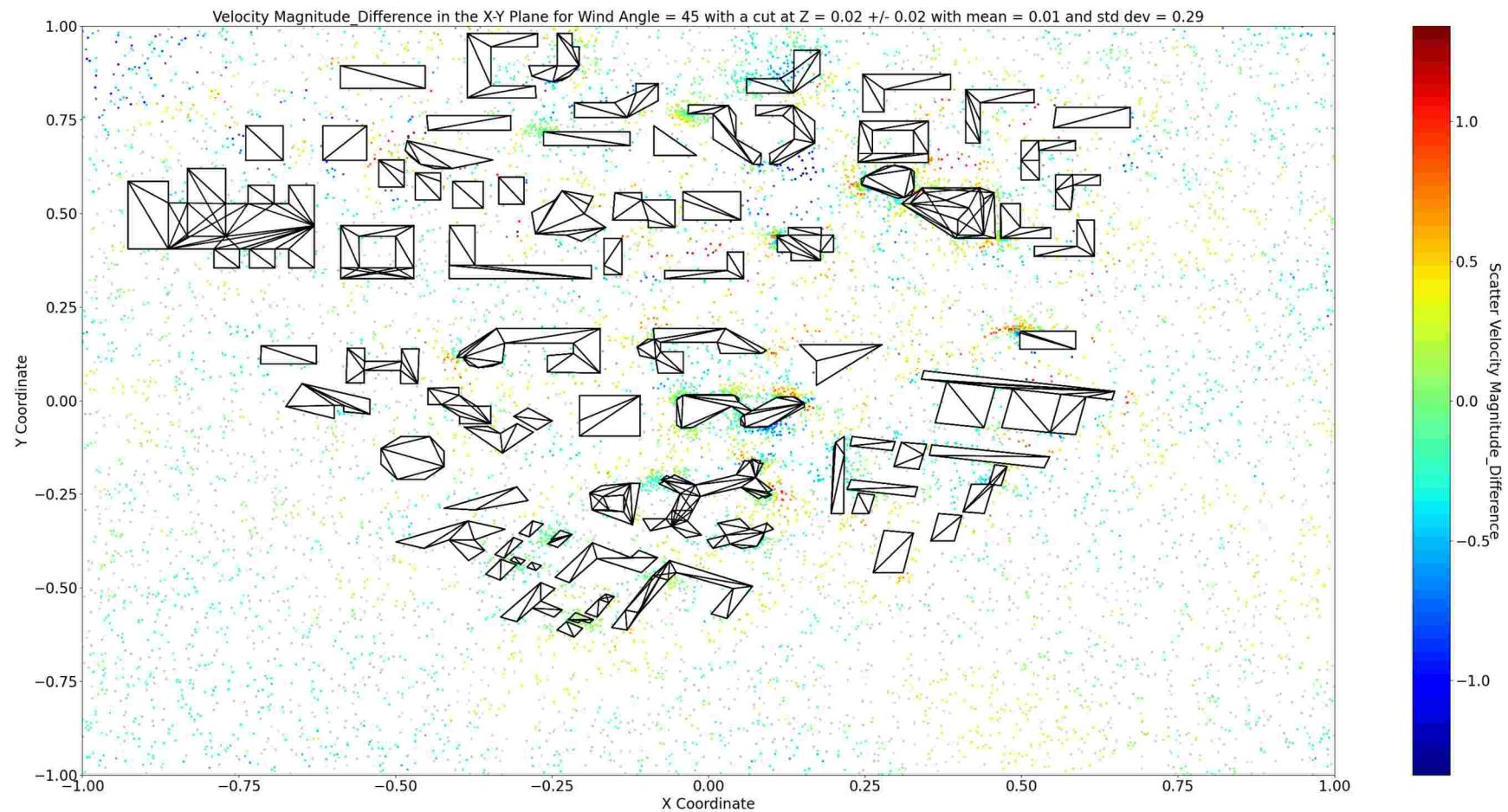
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.02 +/- 0.02
Mean = 0.78 and Standard Deviation = 0.44

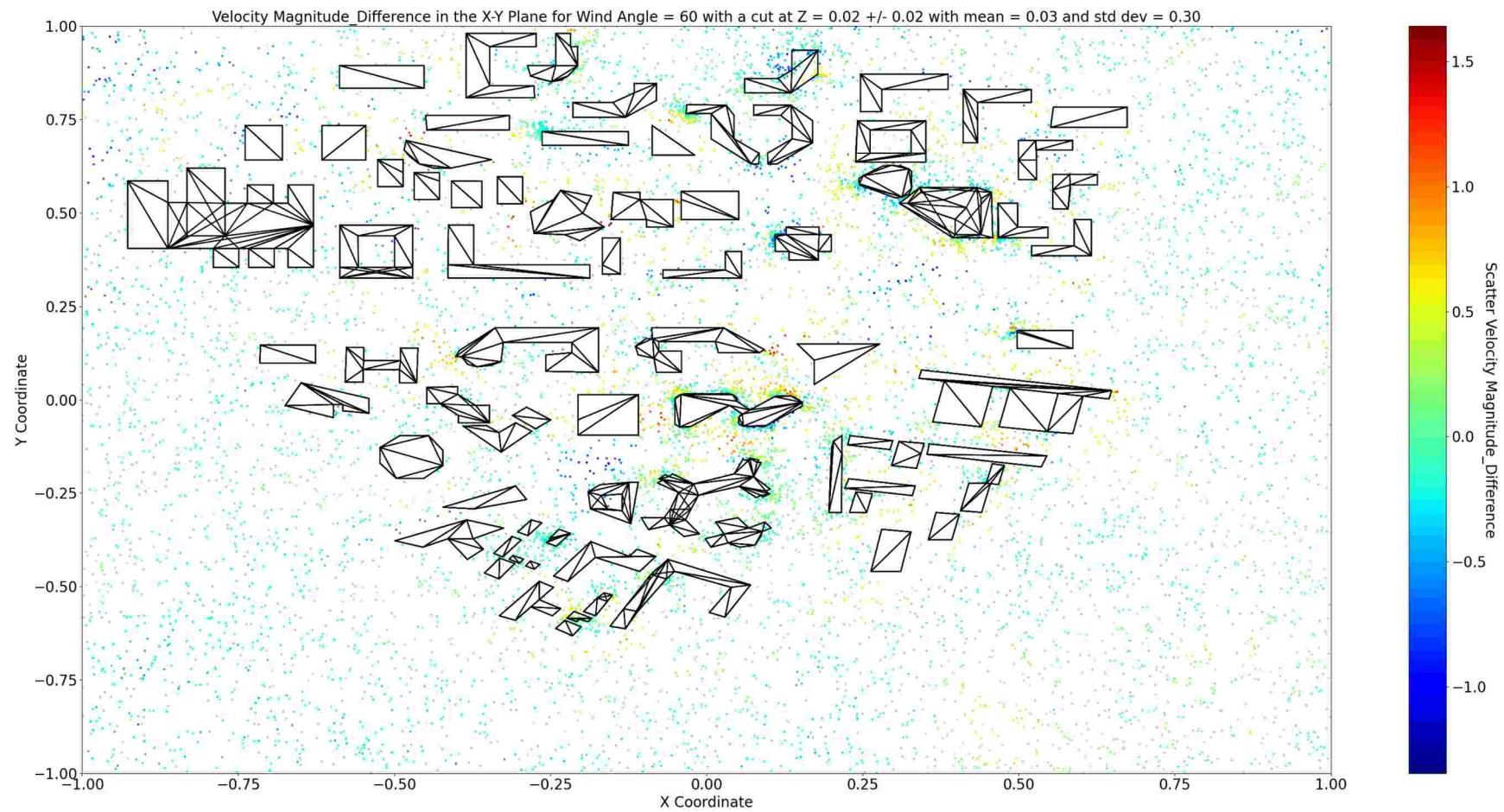


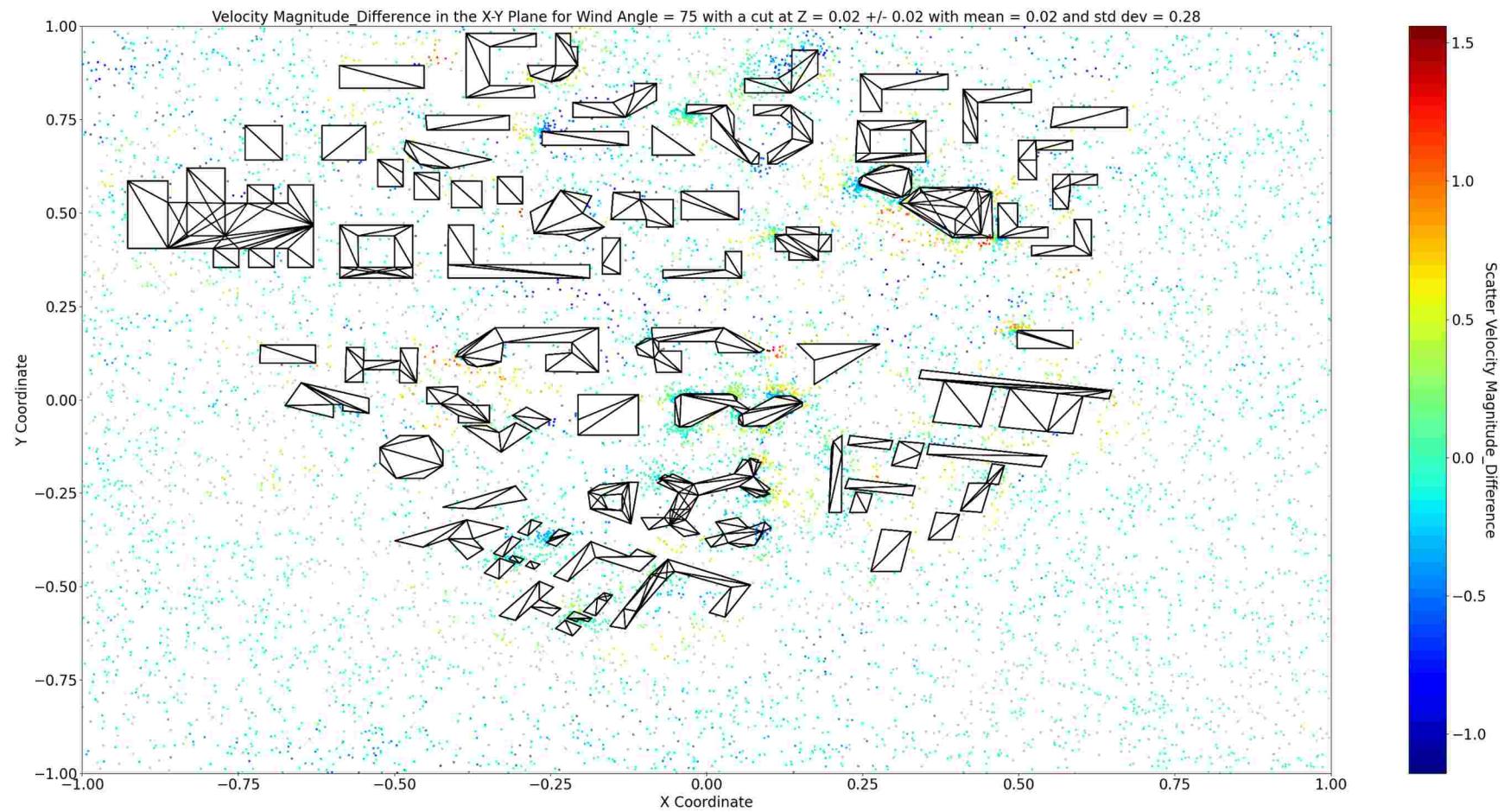


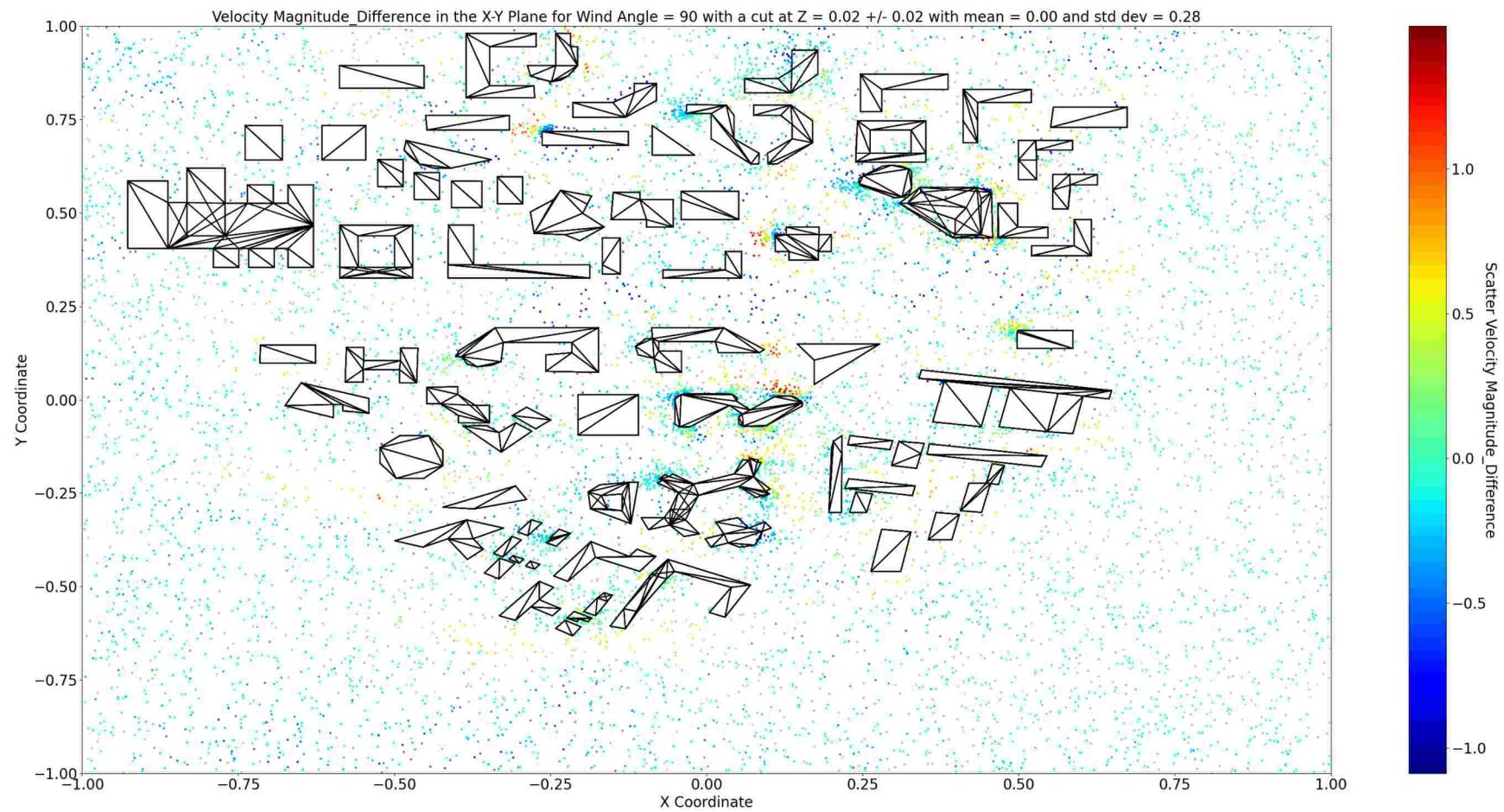


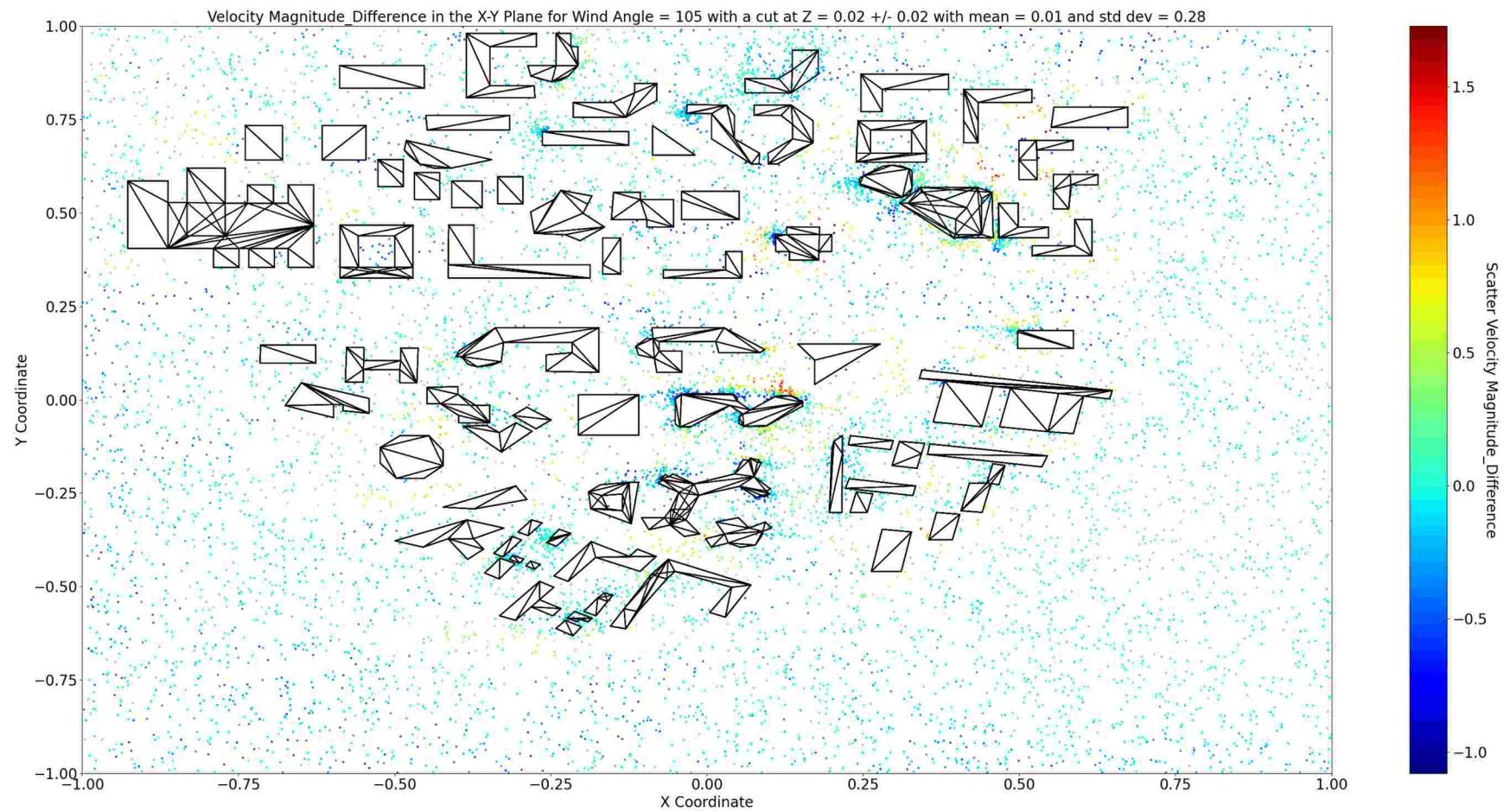


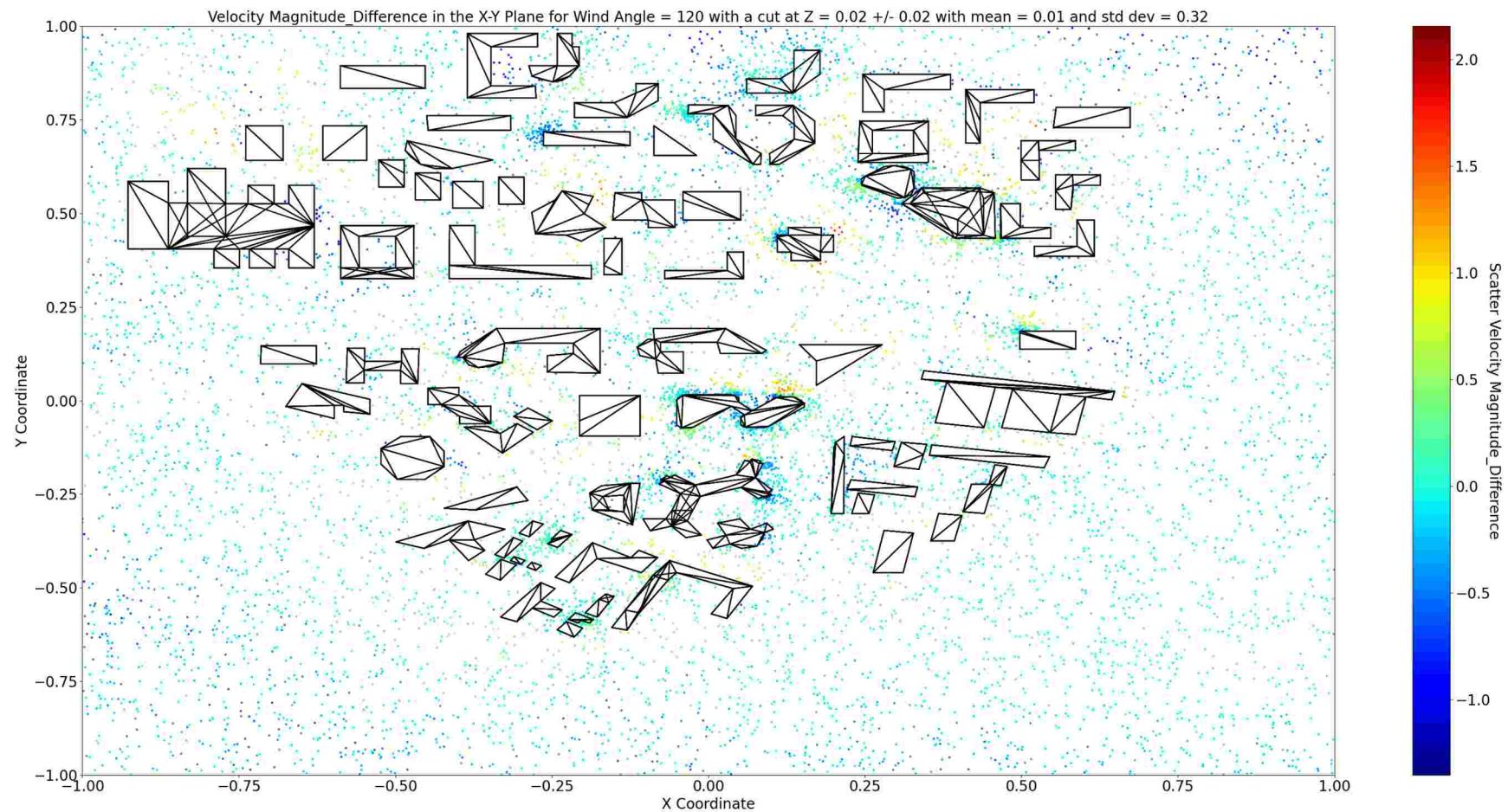




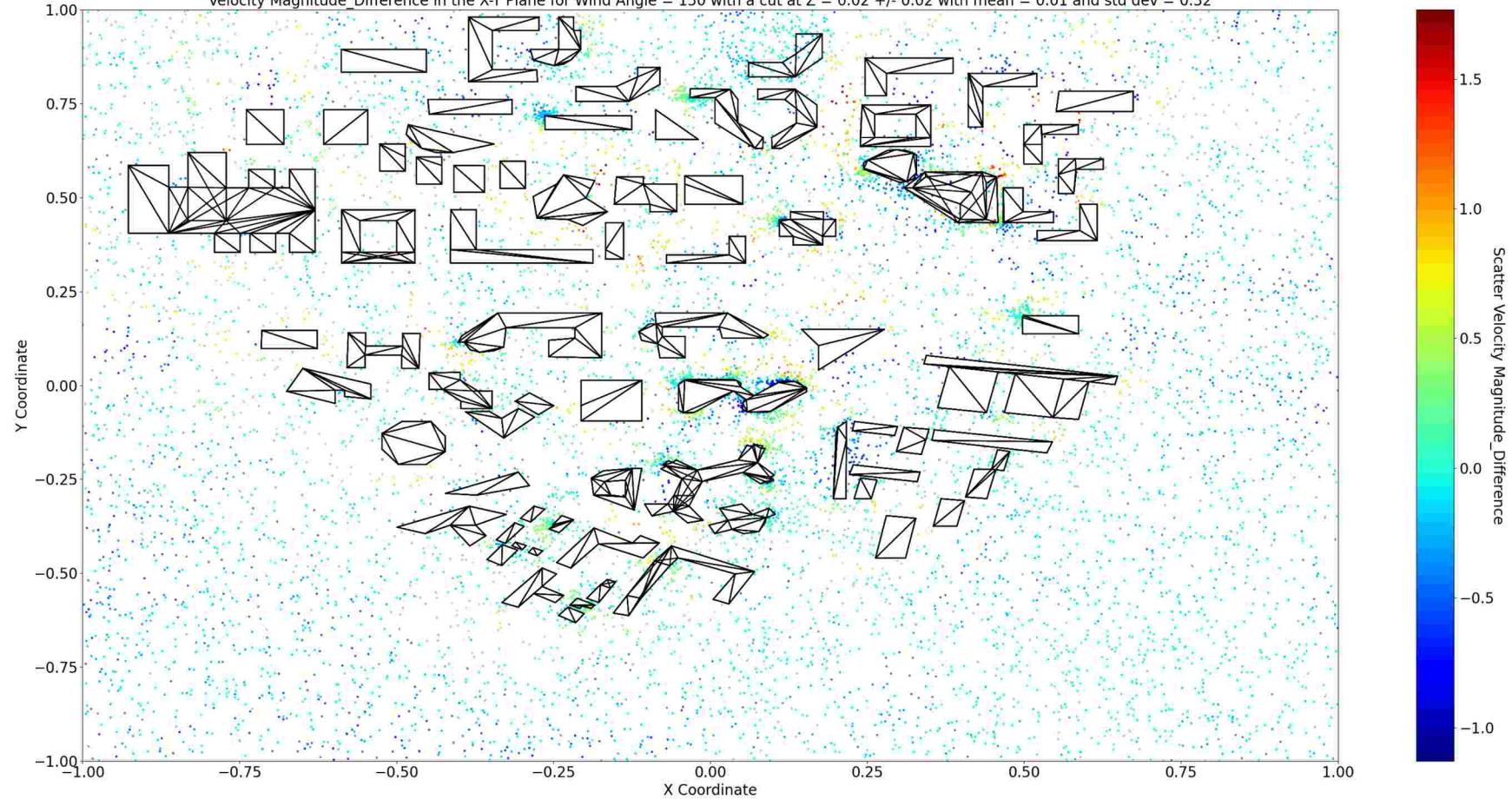


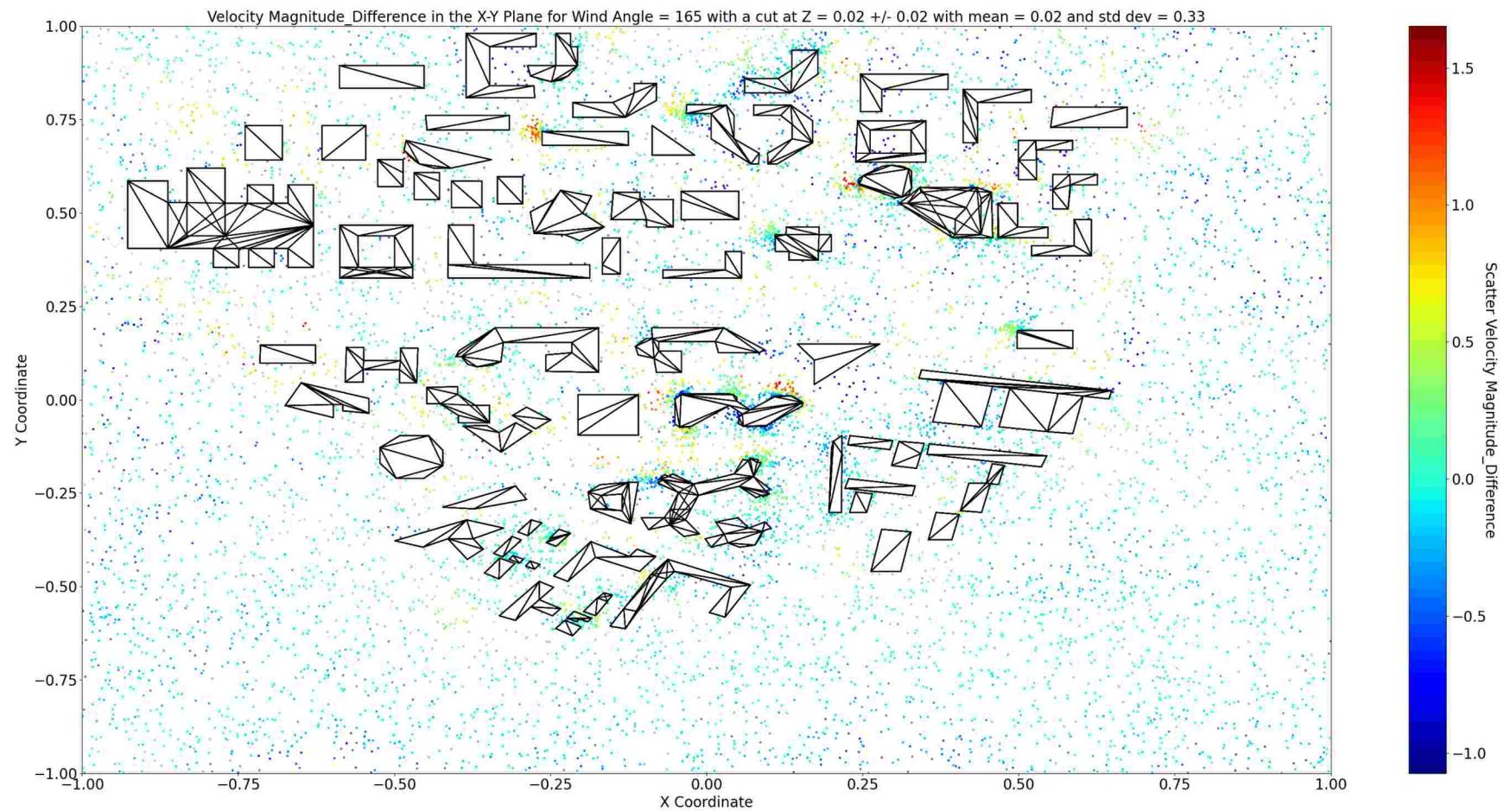


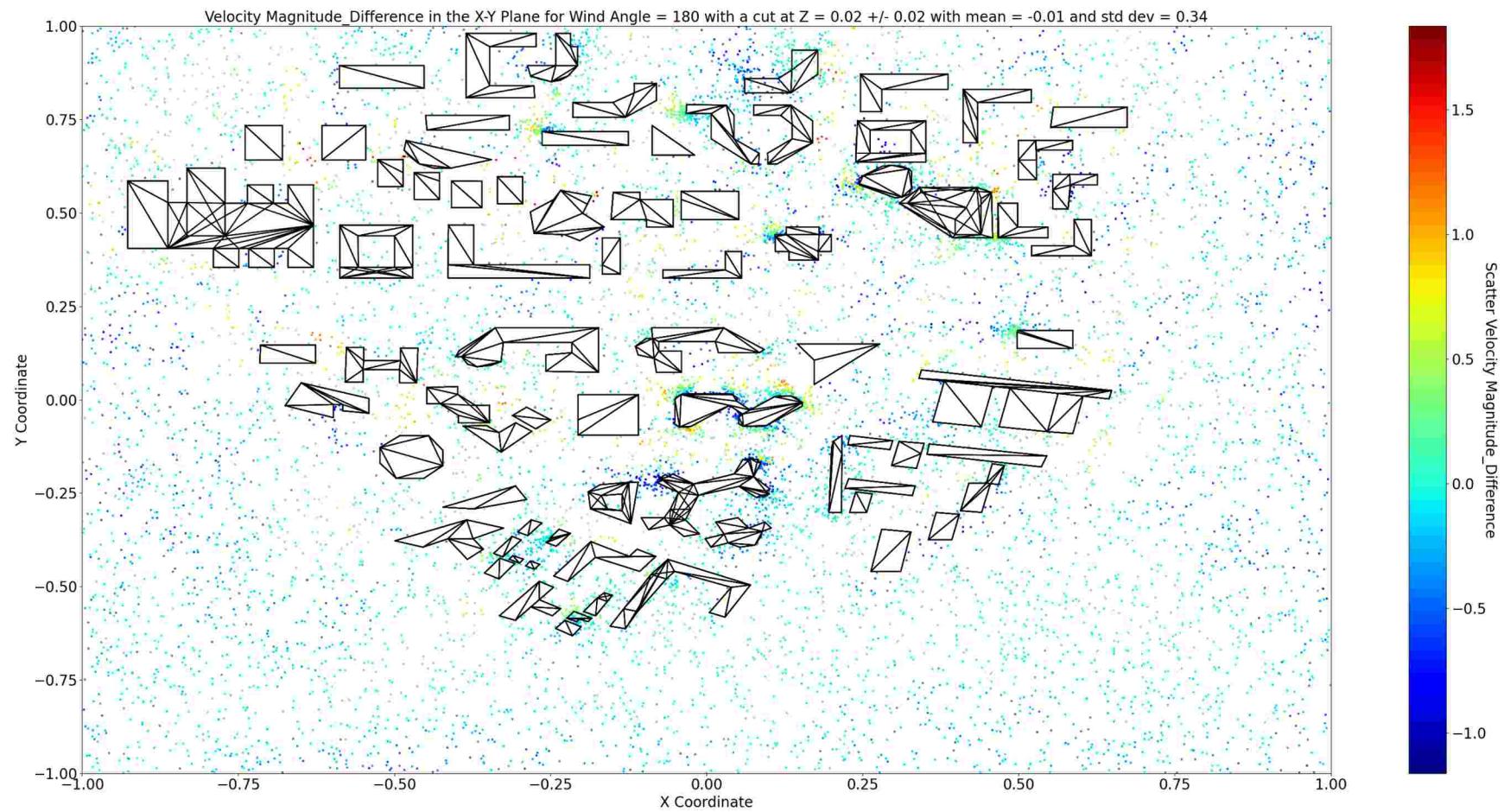




Velocity Magnitude_Difference in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.02 +/- 0.02 with mean = 0.01 and std dev = 0.32







Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (800 Epochs, not completed), Reduced, GPU Laptop

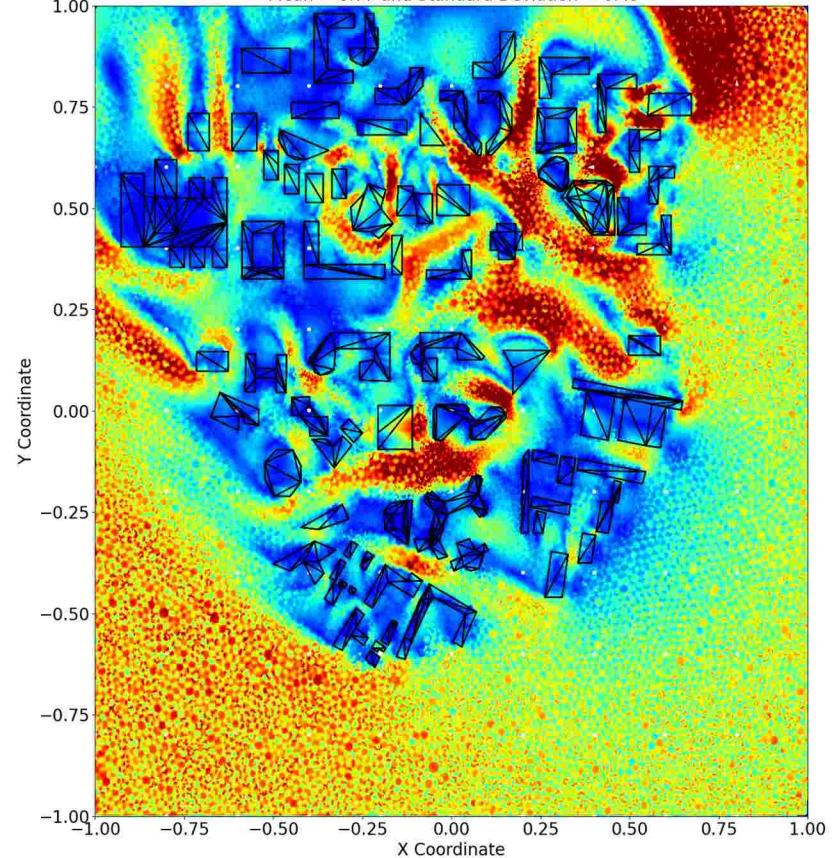
Scripts v5 – PREDICTING

Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (800 Epochs, not completed), GPU Laptop
Predicting Results – Metrics (Angle = 135)

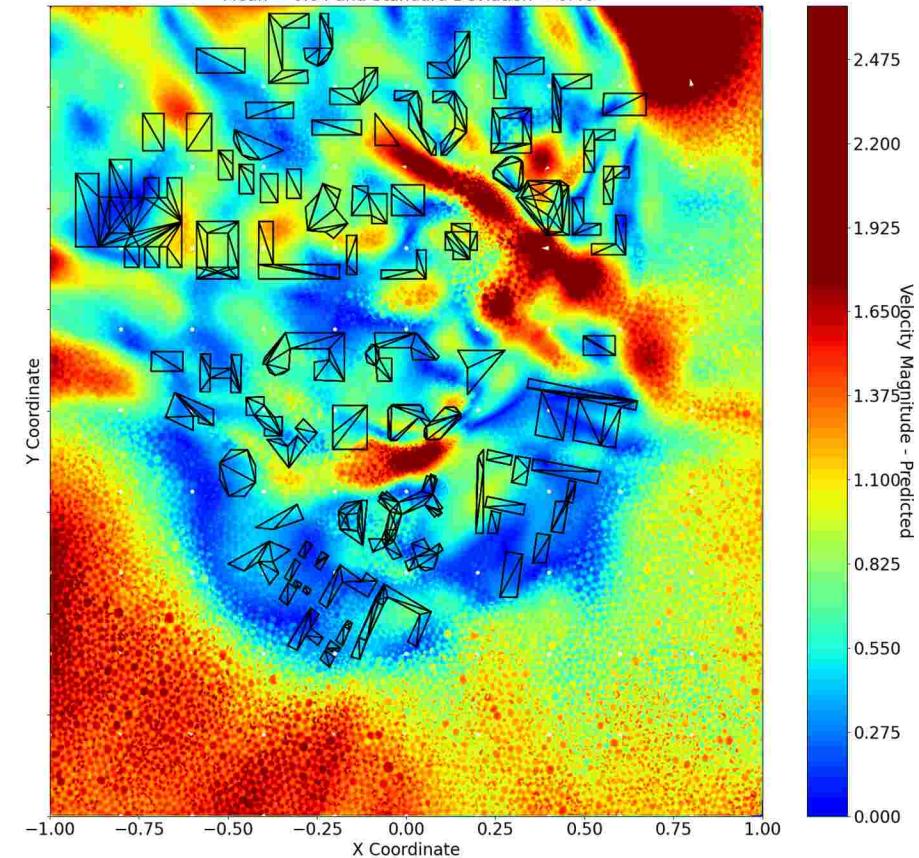
Variable	MSE	RMSE	MAE	R2
Velocity:0	0.21049574	0.45879815	0.38083948	0.85158467
Velocity:1	0.21619749	0.46497042	0.35686982	0.8453996
Velocity:2	0.03959003	0.19897244	0.10459413	0.36486499

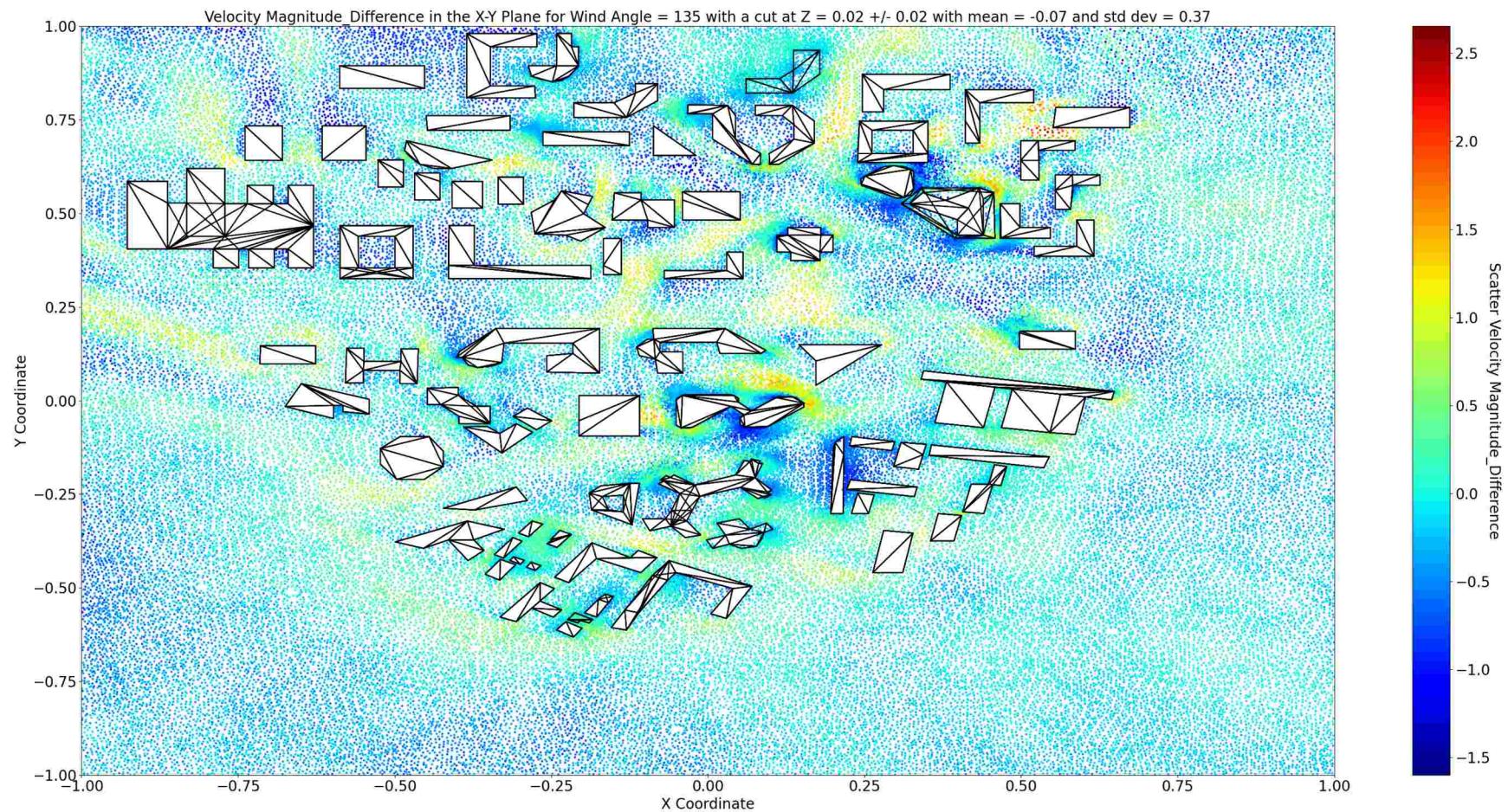
Comparison of Actual vs. Predicted values with Wind Angle = 135 in the X-Y Plane with a cut at Z = 0.02 +/- 0.02

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.02 +/- 0.02
Mean = 0.77 and Standard Deviation = 0.49



Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.02 +/- 0.02
Mean = 0.84 and Standard Deviation = 0.46





Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (9 Epochs, not completed), Full Dataset, A100 GPU

Scripts v5 – TESTING

Some Parameters

Infinite epochs - Simple Moving Average stopping condition

128 Neurons for the PINN unless otherwise specified (50949 parameters in total)

We have the data for 13 angles, [0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180] in degrees

We concatenate the data for angles = [0, 15, 30, 45, 60, 75, 90, 105, 120, 150, 165, 180] and then take 99% of the dataset with random seed = 42 for training and 1% for testing

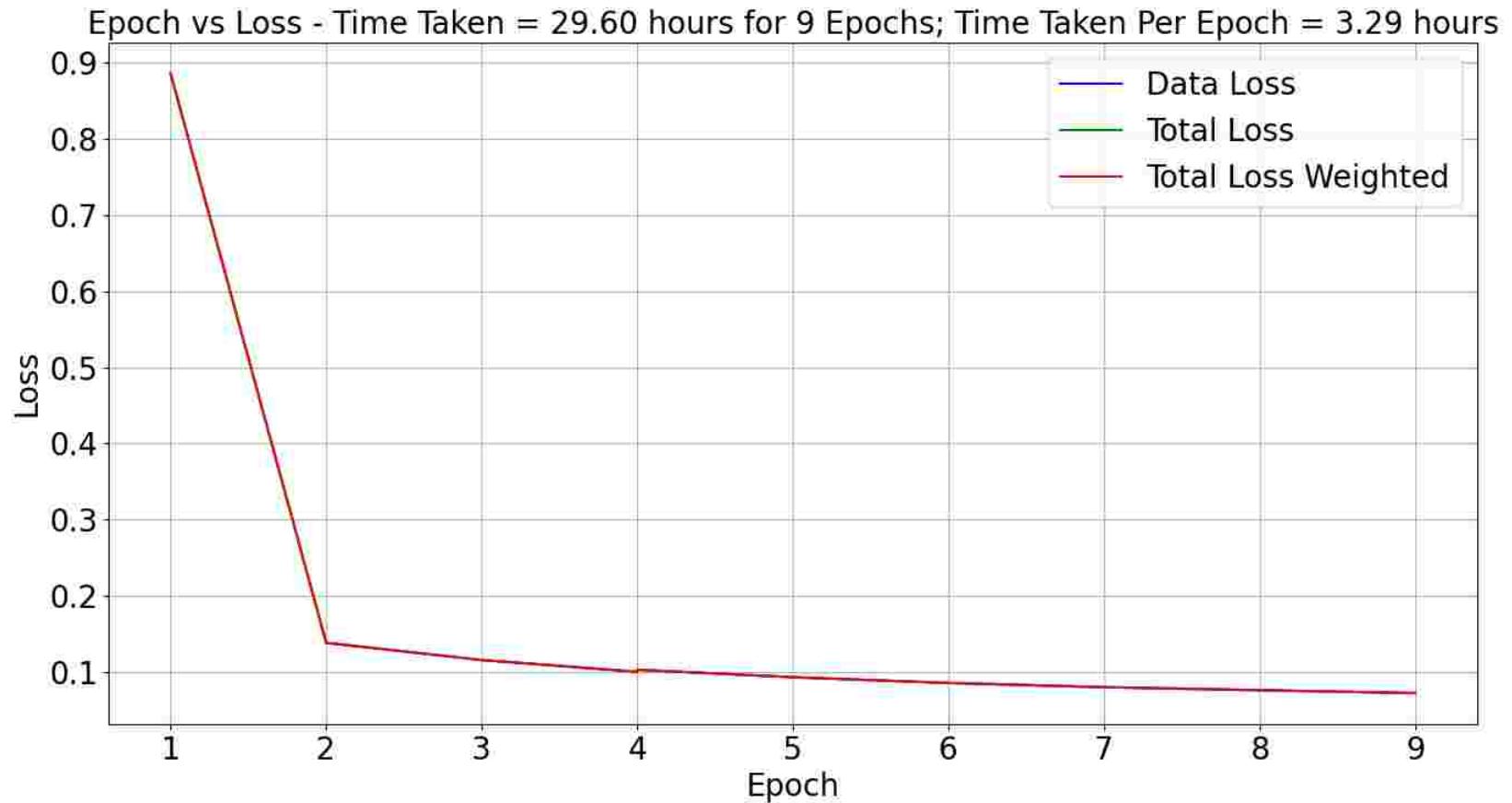
By using 99% of the whole dataset we hope to make the NN learn about wind angle such that the parameters become functions of the wind angle

Then using the trained neural network we predict the data for angle = 135

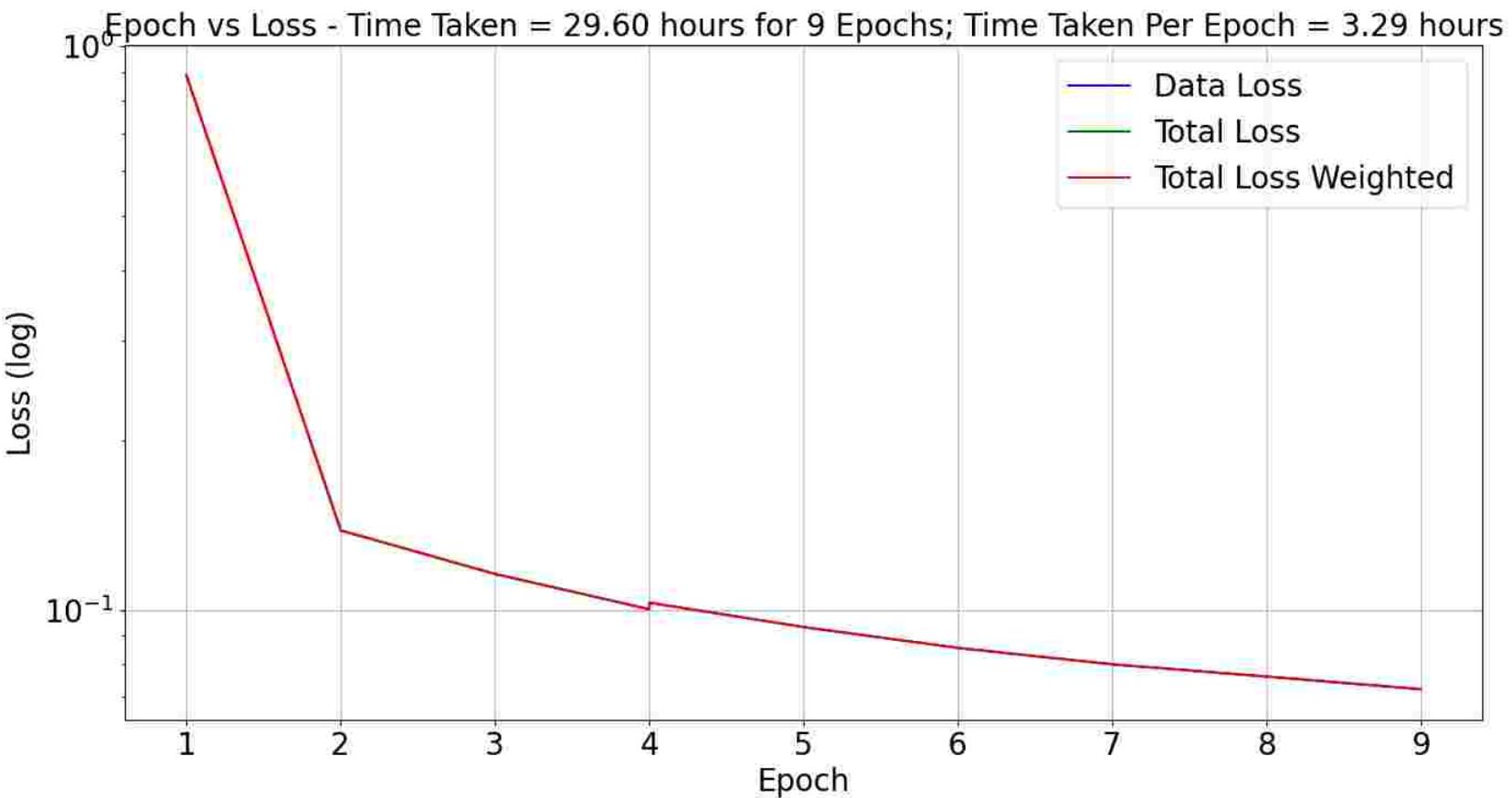
For this run, we will only have input parameters to be [X, Y, Z, $\cos(\theta)$, $\sin(\theta)$] and the output parameters will be [U, V, W]

Total Number of Data Points → 1.21954E7 points per wind angle * (5 inputs + 3 outputs) * (12 training wind angles) ~ 1.17E9
(~1.46E9 if we include Pressure and TurbVisc)

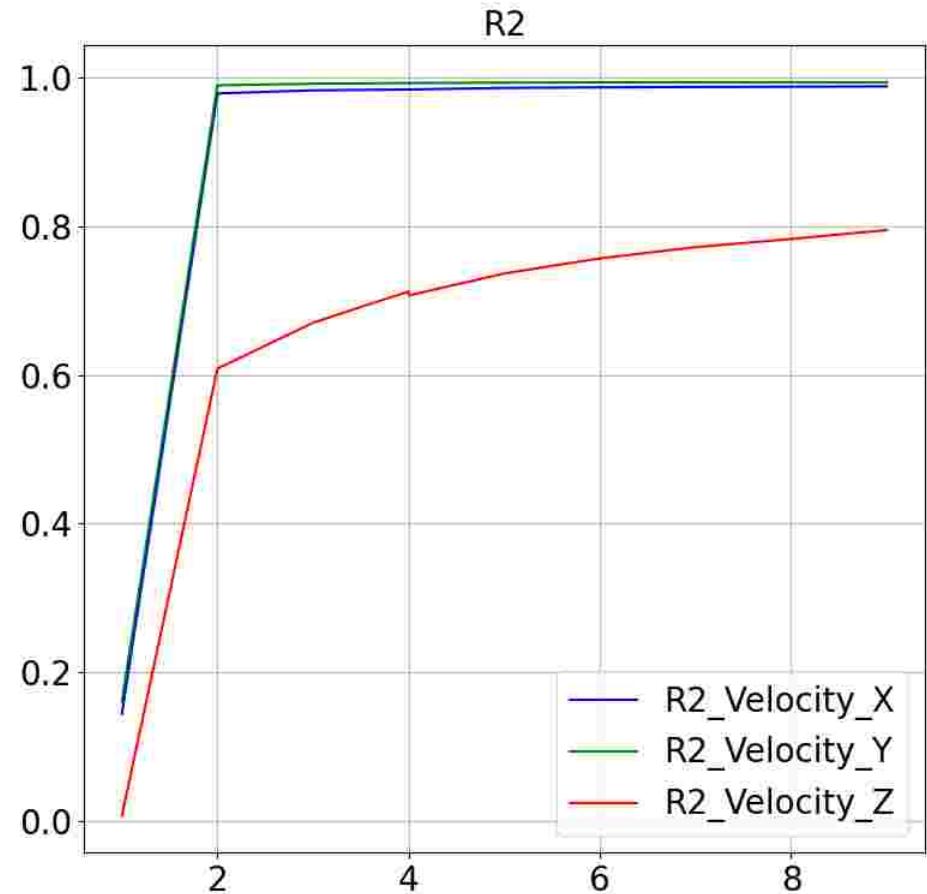
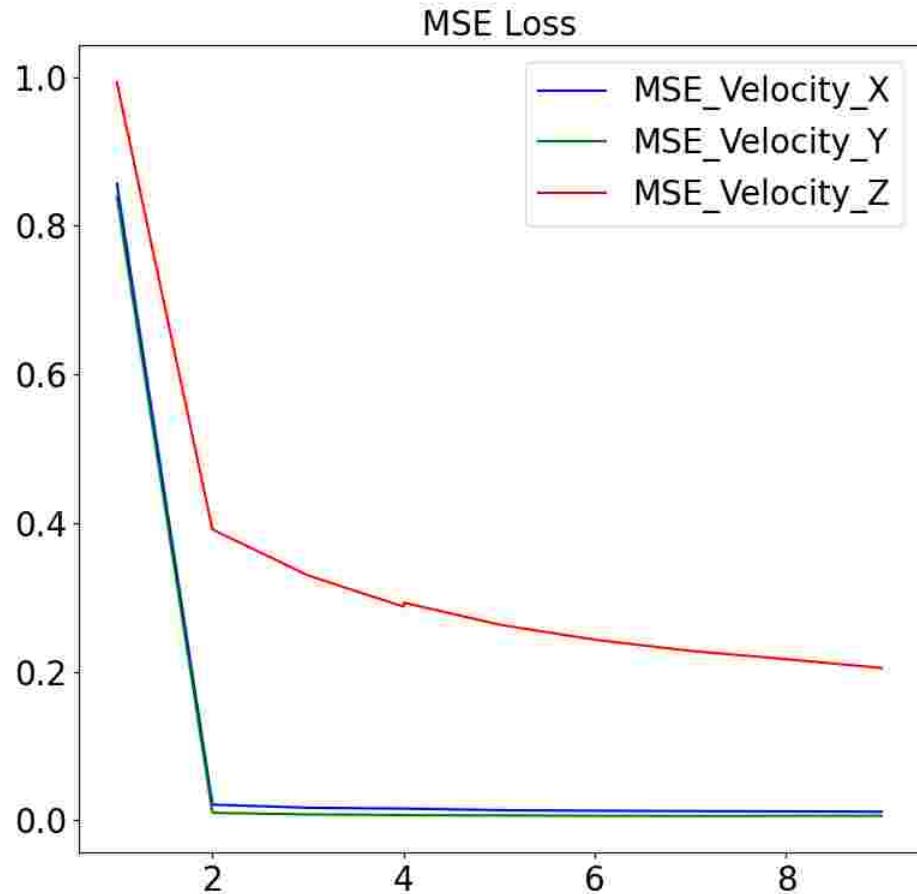
Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (9 Epochs, not completed), A100 GPU
Logging Plots (Training)



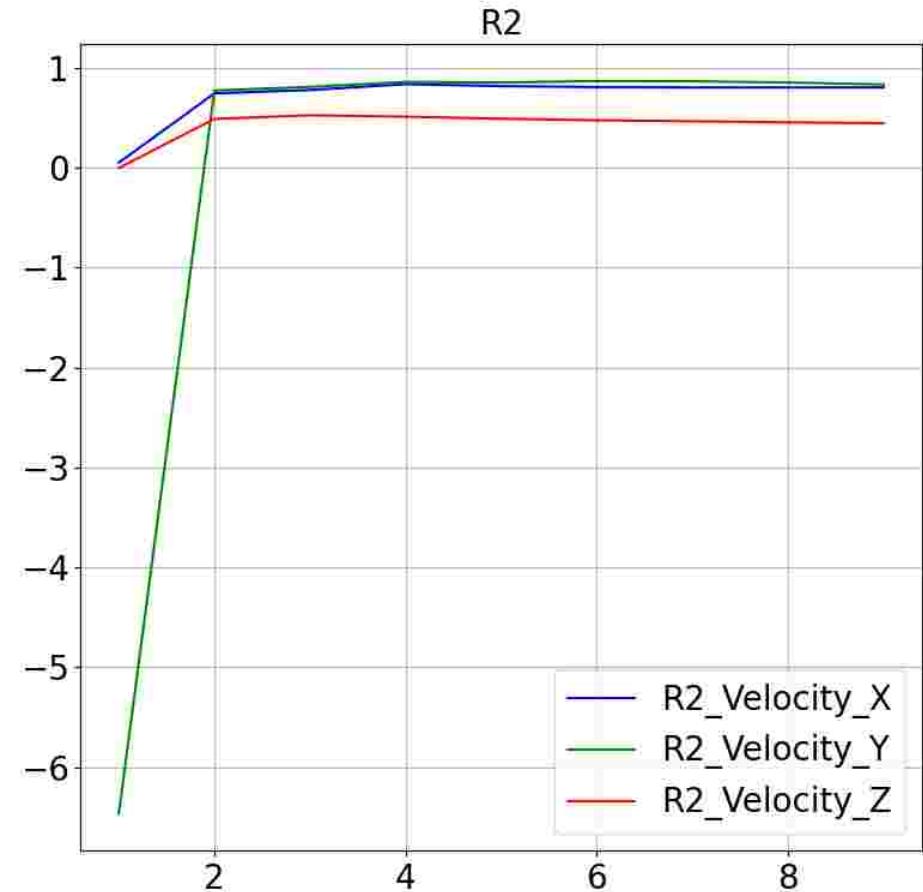
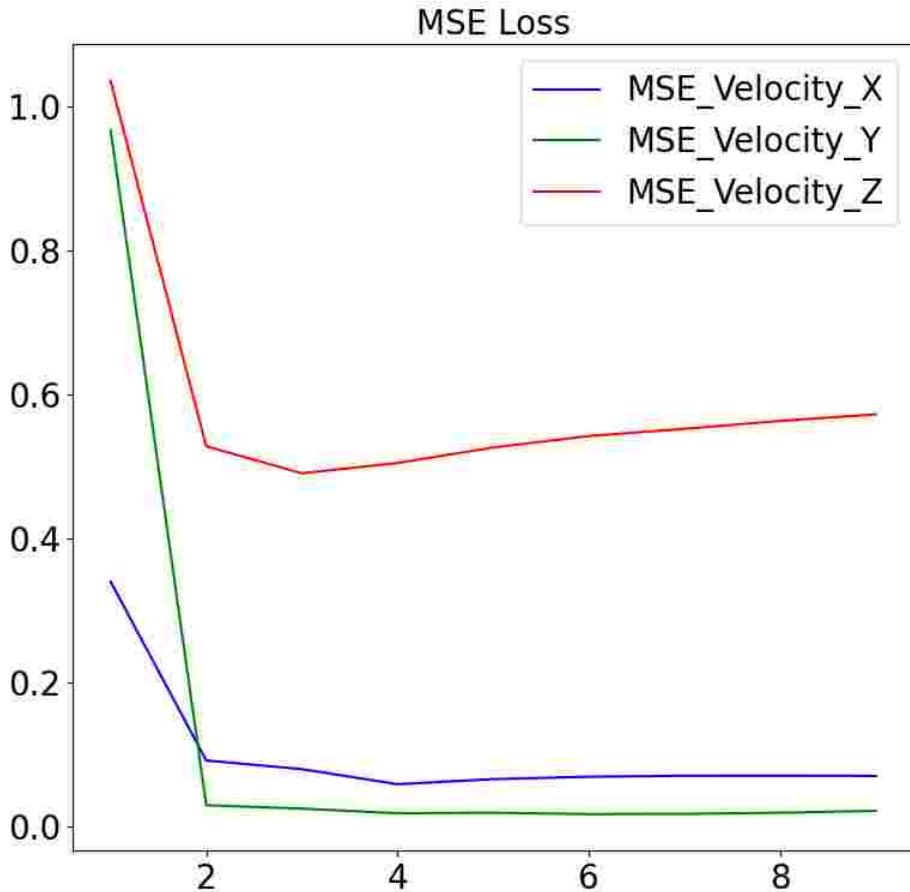
Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (9 Epochs, not completed), A100 GPU
Logging Plots (Training)



Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (9 Epochs, not completed), A100 GPU
Logging Plots (Testing)

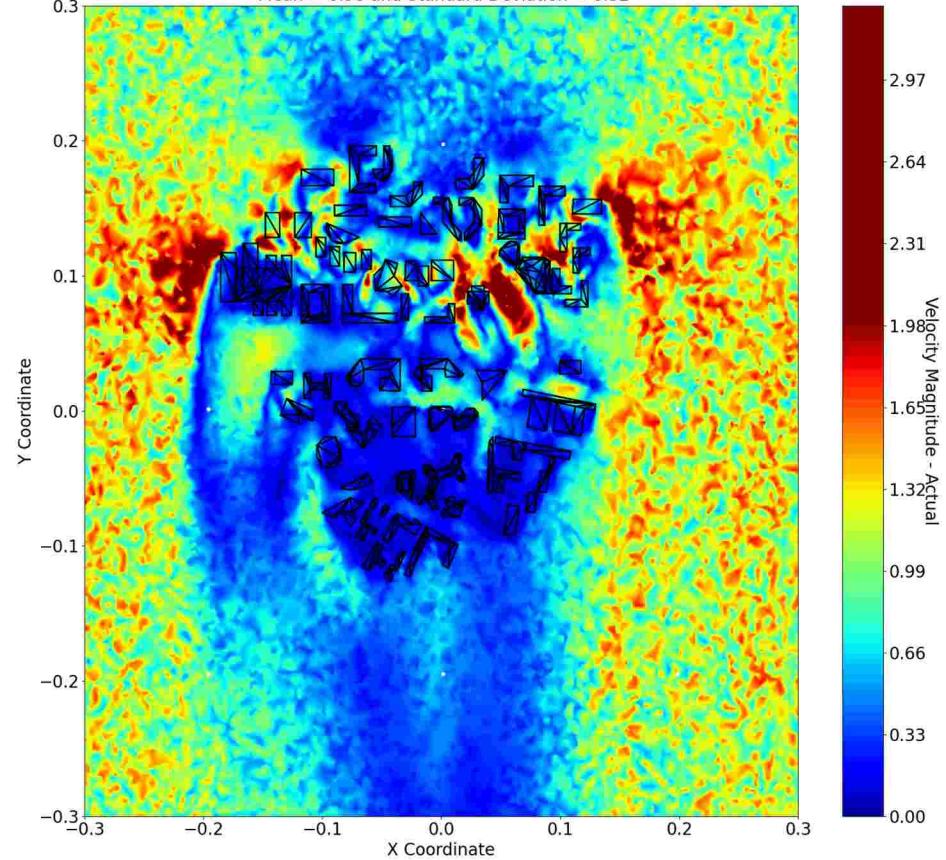


Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (9 Epochs, not completed), A100 GPU
Logging Plots (Predicting 135)

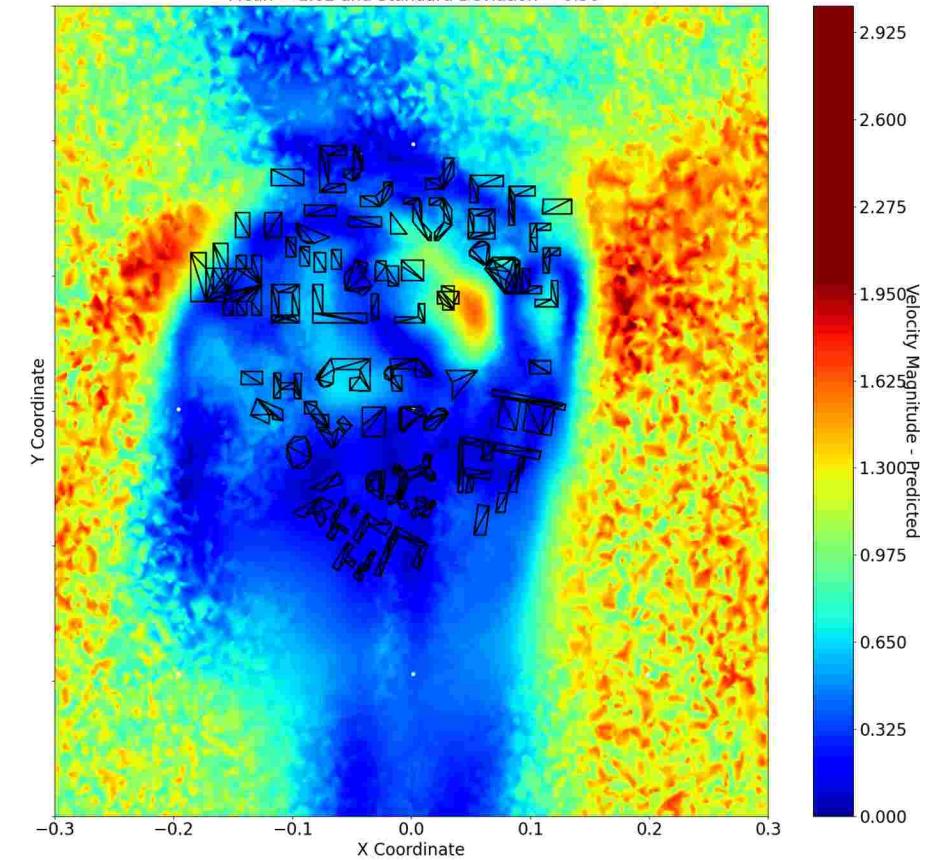


Comparison of Actual vs. Predicted values with Wind Angle = 0 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01
Mean = 0.98 and Standard Deviation = 0.52

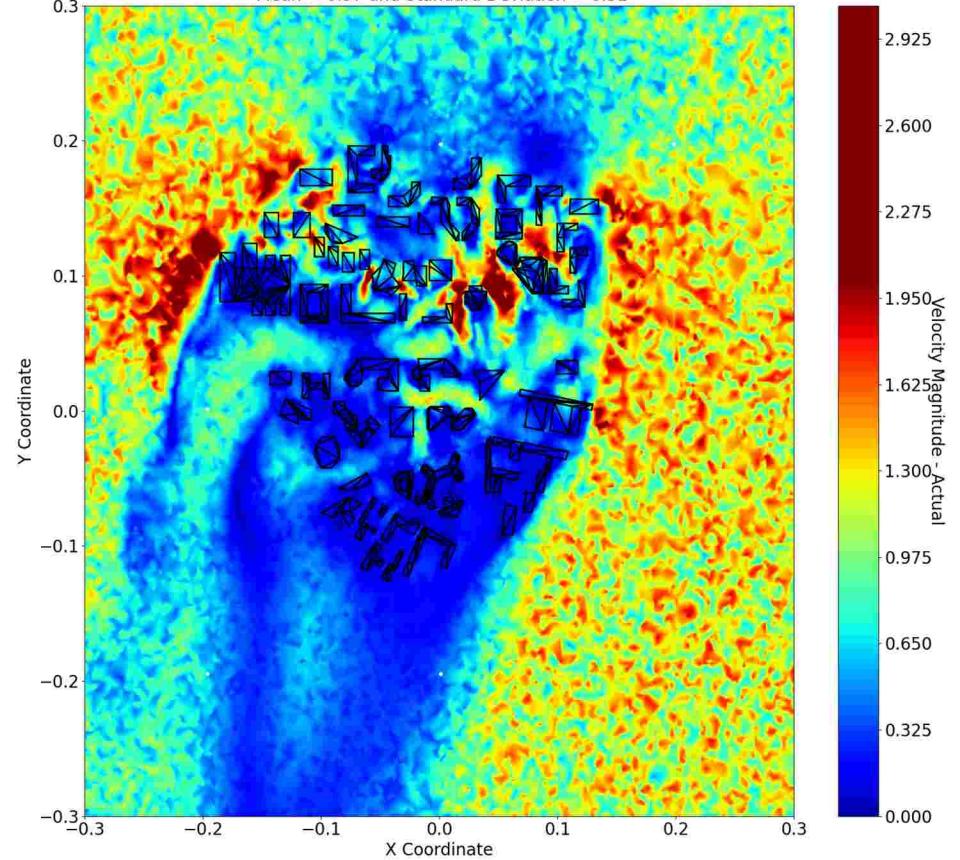


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.50

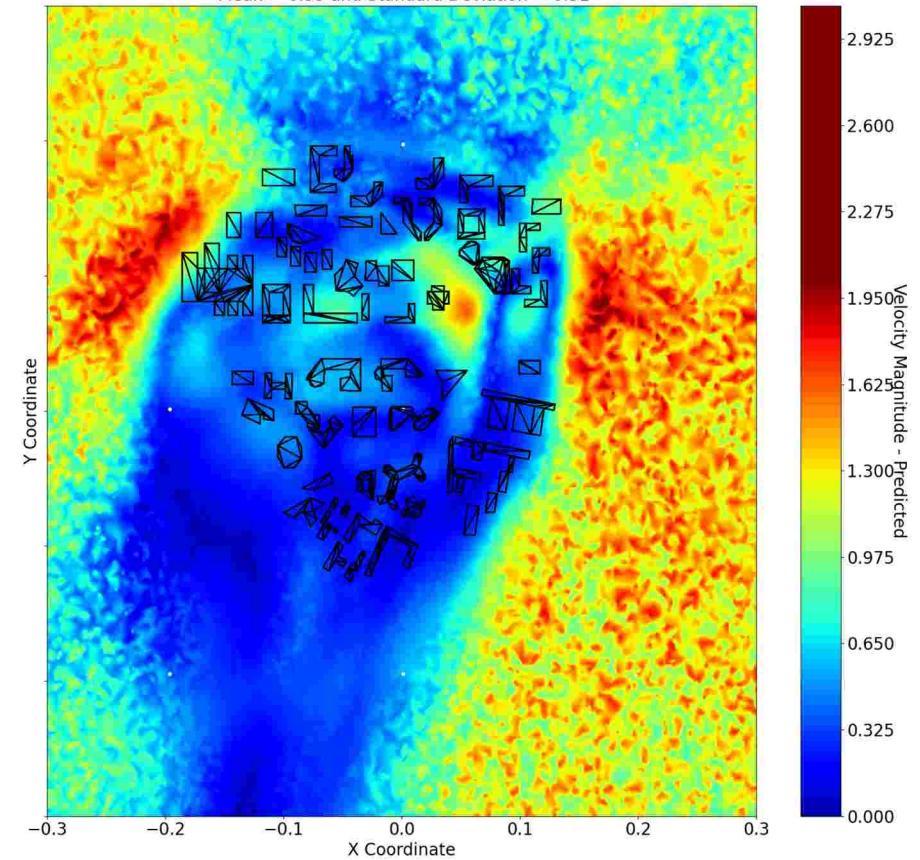


Comparison of Actual vs. Predicted values with Wind Angle = 15 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01
Mean = 0.97 and Standard Deviation = 0.52

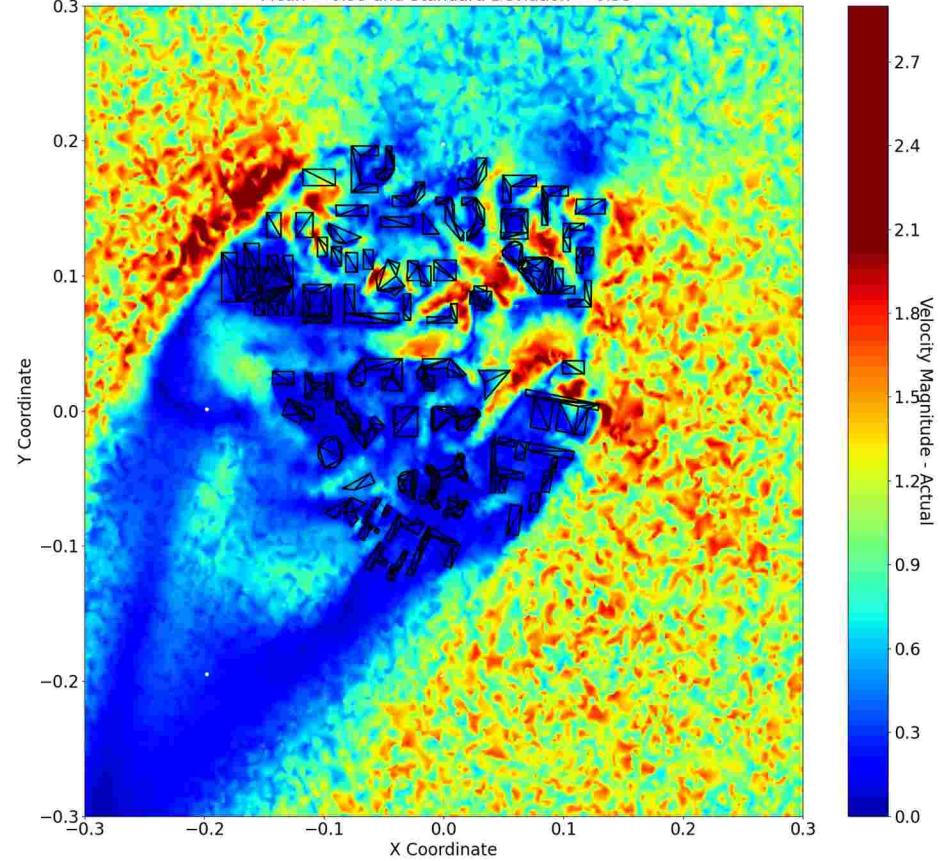


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01
Mean = 0.99 and Standard Deviation = 0.51

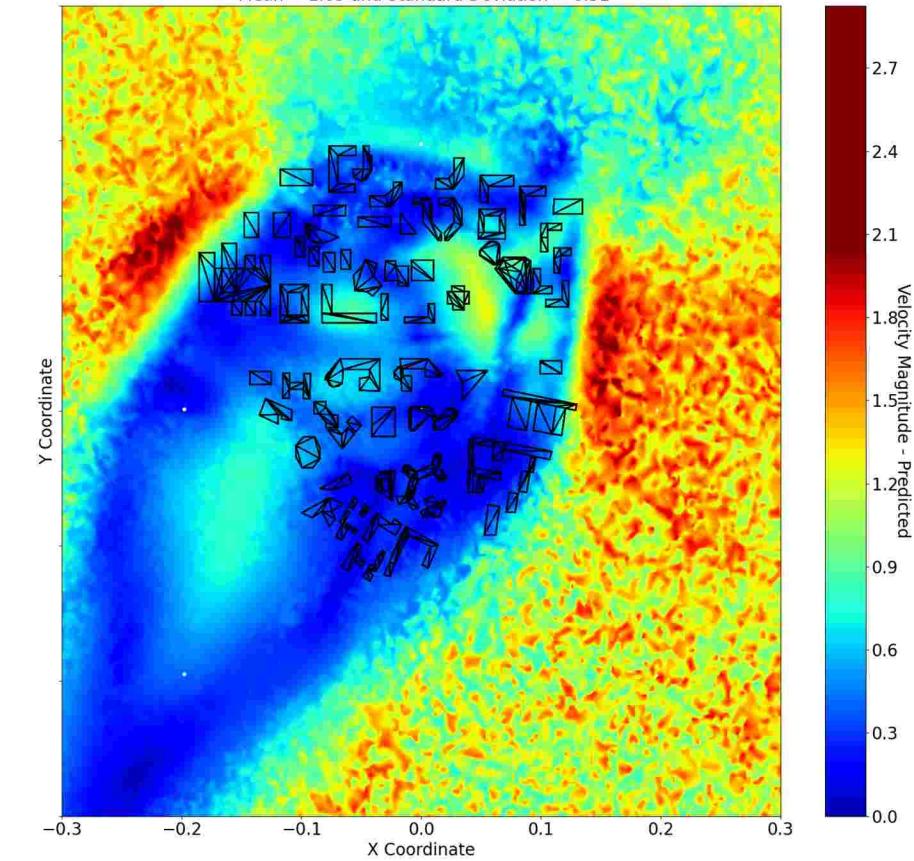


Comparison of Actual vs. Predicted values with Wind Angle = 30 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01
Mean = 0.99 and Standard Deviation = 0.53

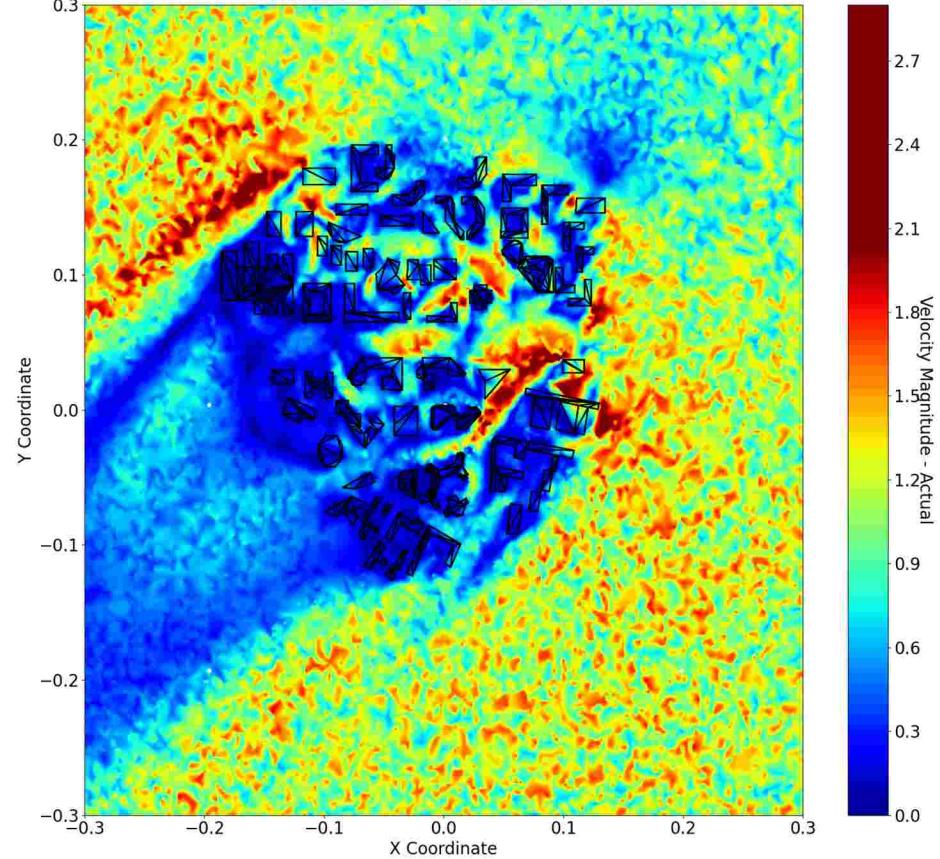


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01
Mean = 1.05 and Standard Deviation = 0.51

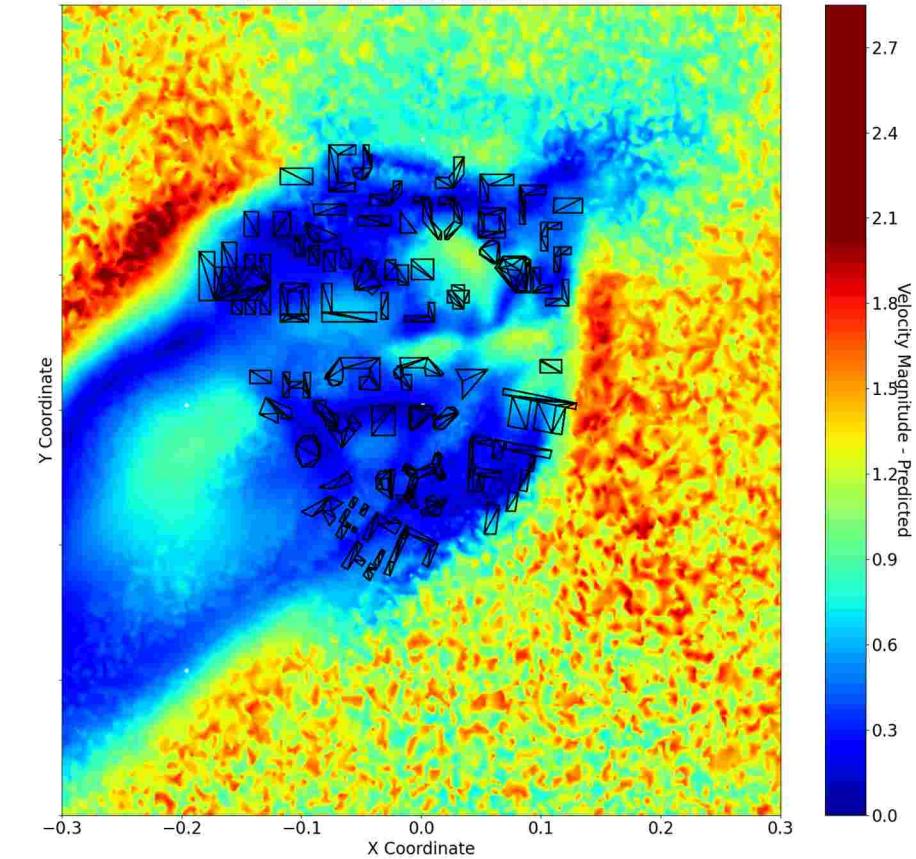


Comparison of Actual vs. Predicted values with Wind Angle = 45 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.51

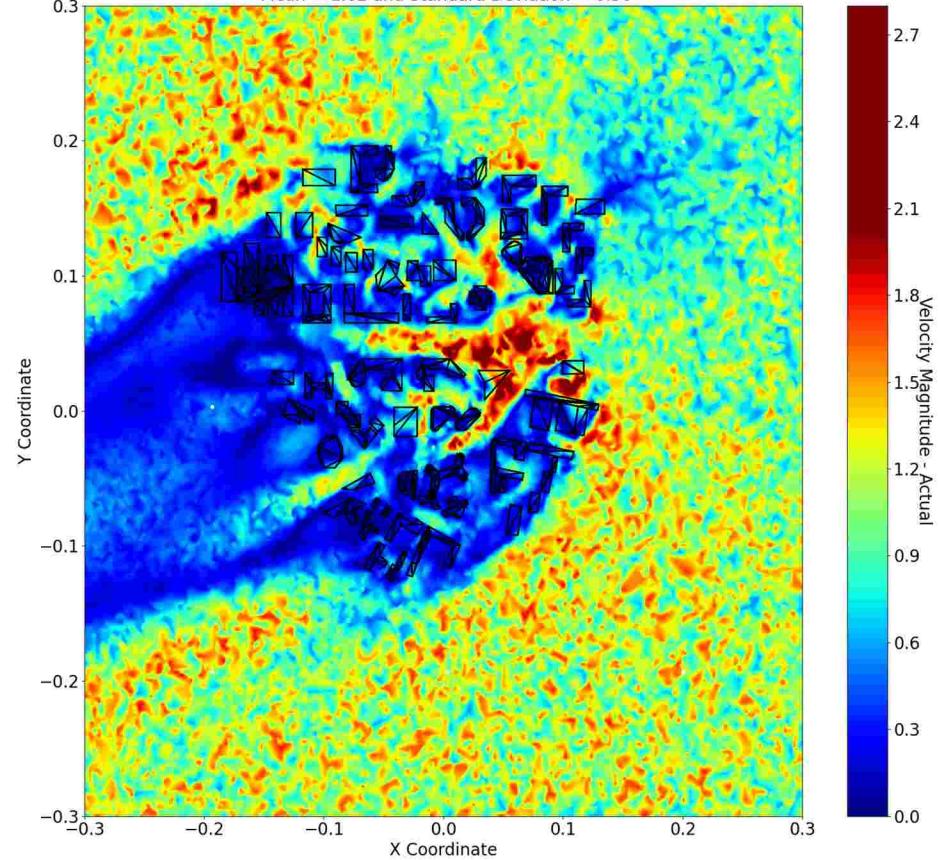


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 45 with a cut at Z = 0.01 +/- 0.01
Mean = 1.10 and Standard Deviation = 0.51

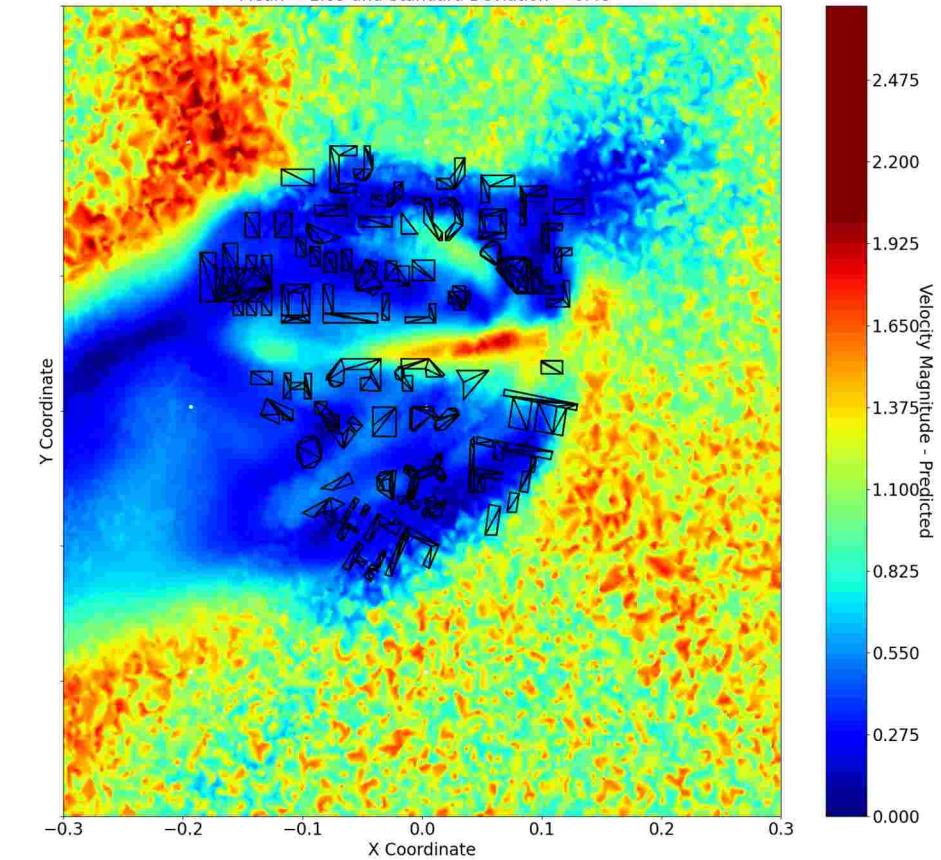


Comparison of Actual vs. Predicted values with Wind Angle = 60 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.50

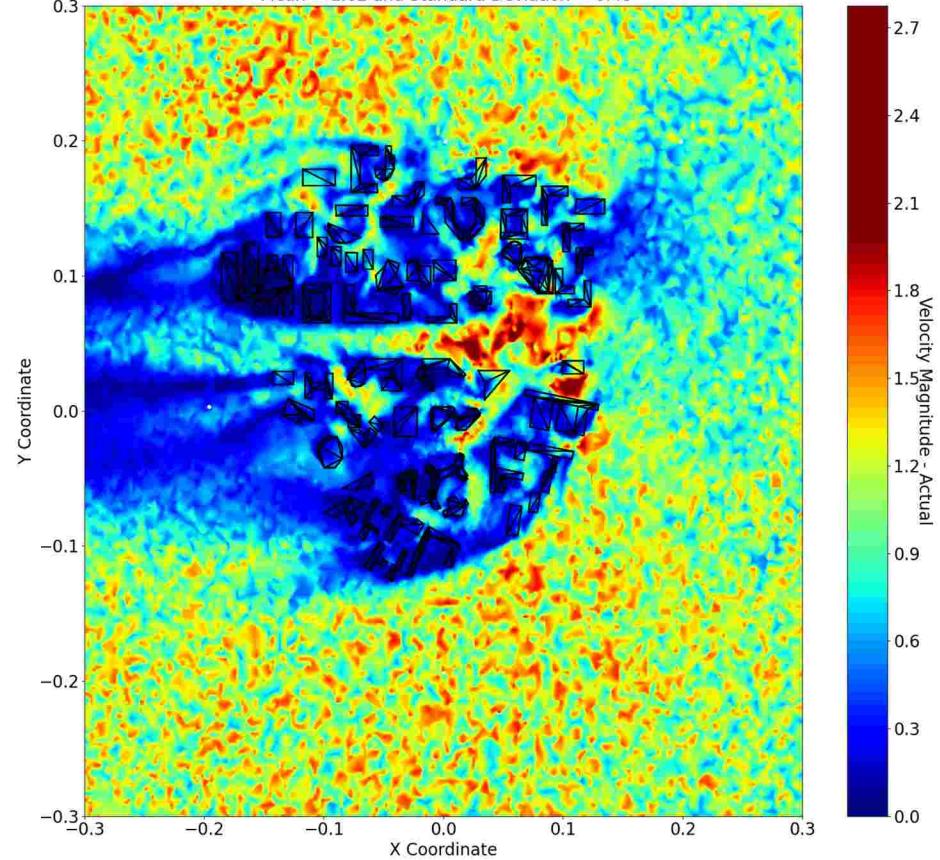


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01
Mean = 1.09 and Standard Deviation = 0.48

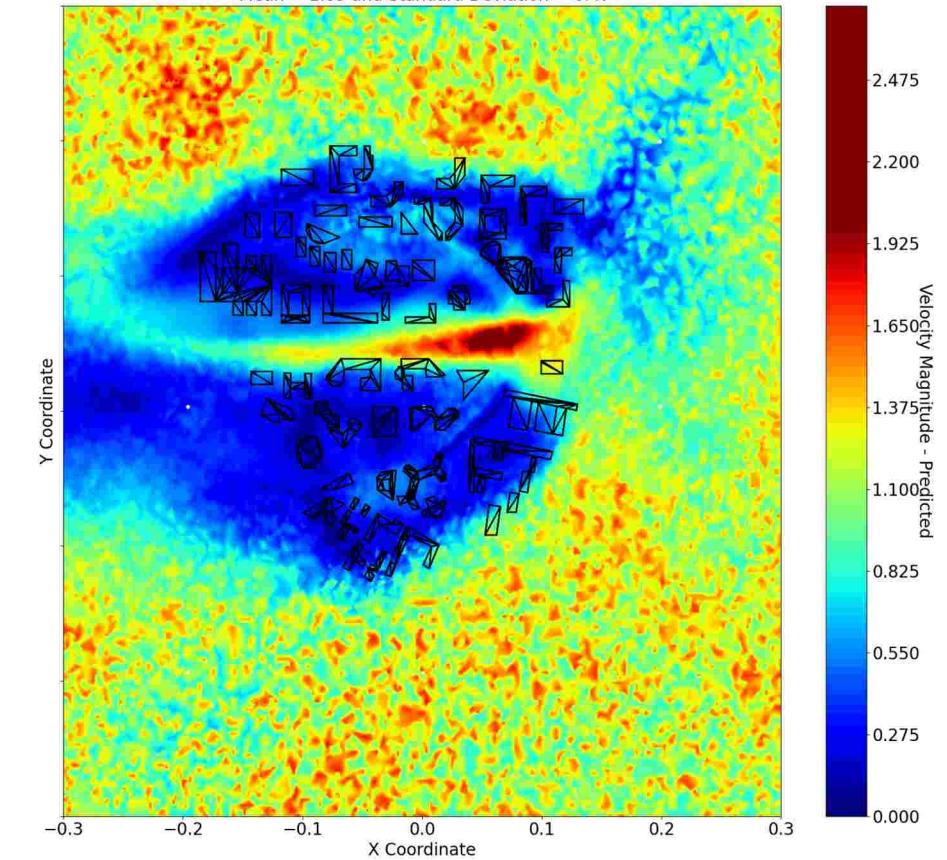


Comparison of Actual vs. Predicted values with Wind Angle = 75 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.48

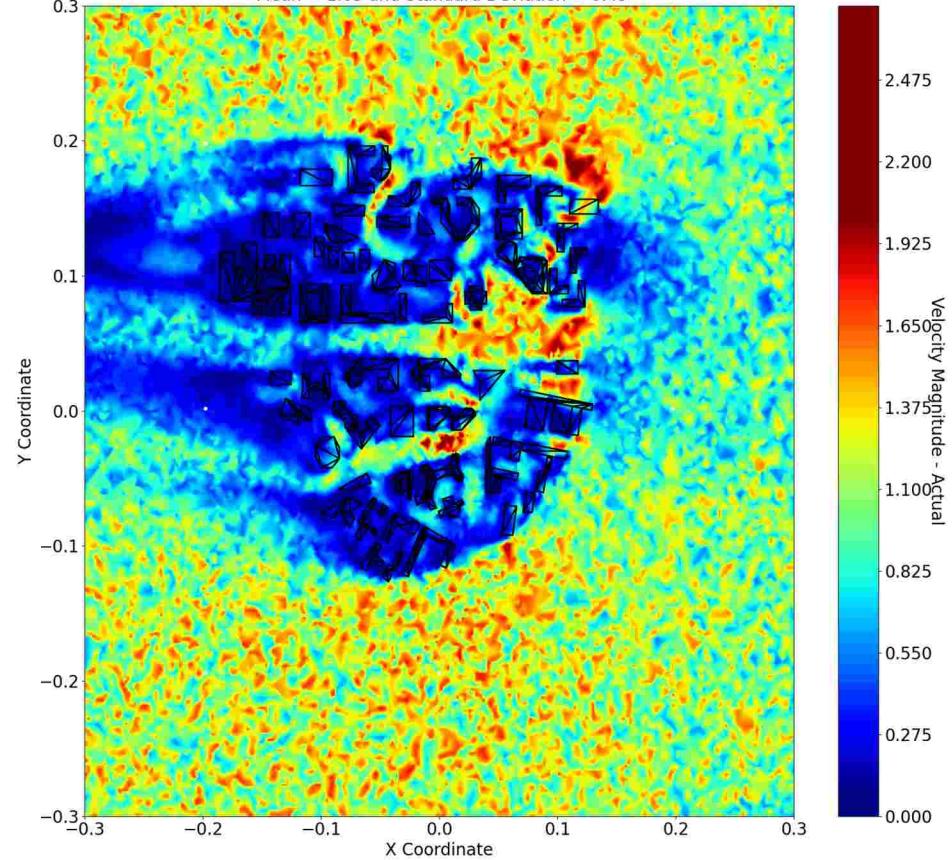


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01
Mean = 1.09 and Standard Deviation = 0.47

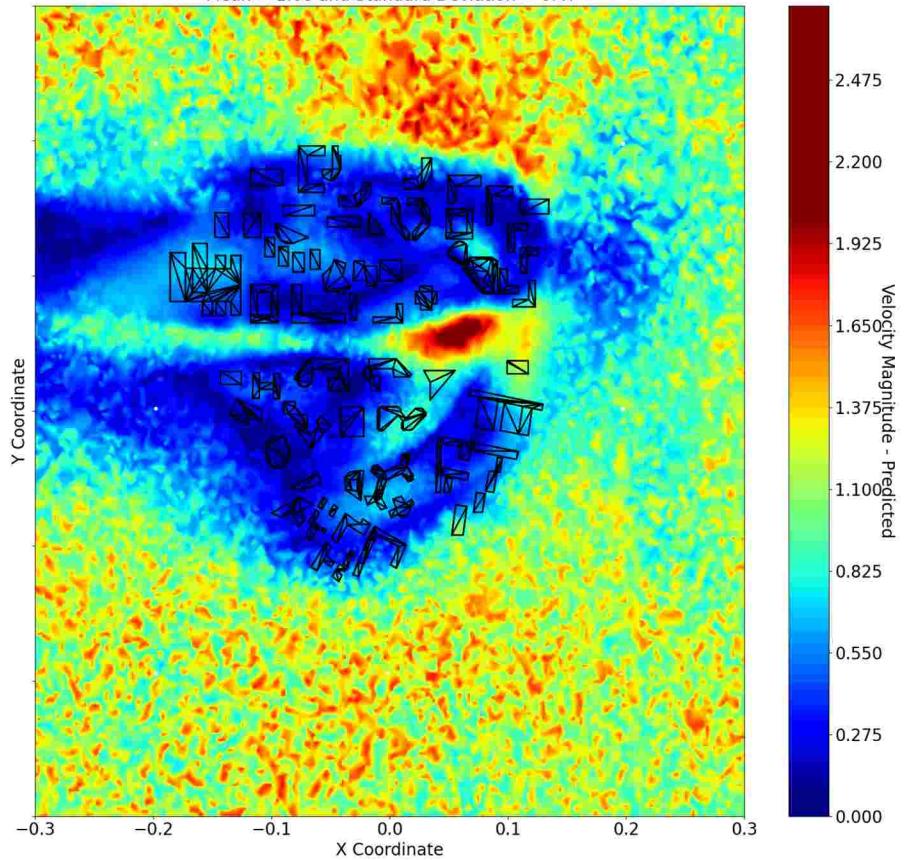


Comparison of Actual vs. Predicted values with Wind Angle = 90 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01
Mean = 1.03 and Standard Deviation = 0.49

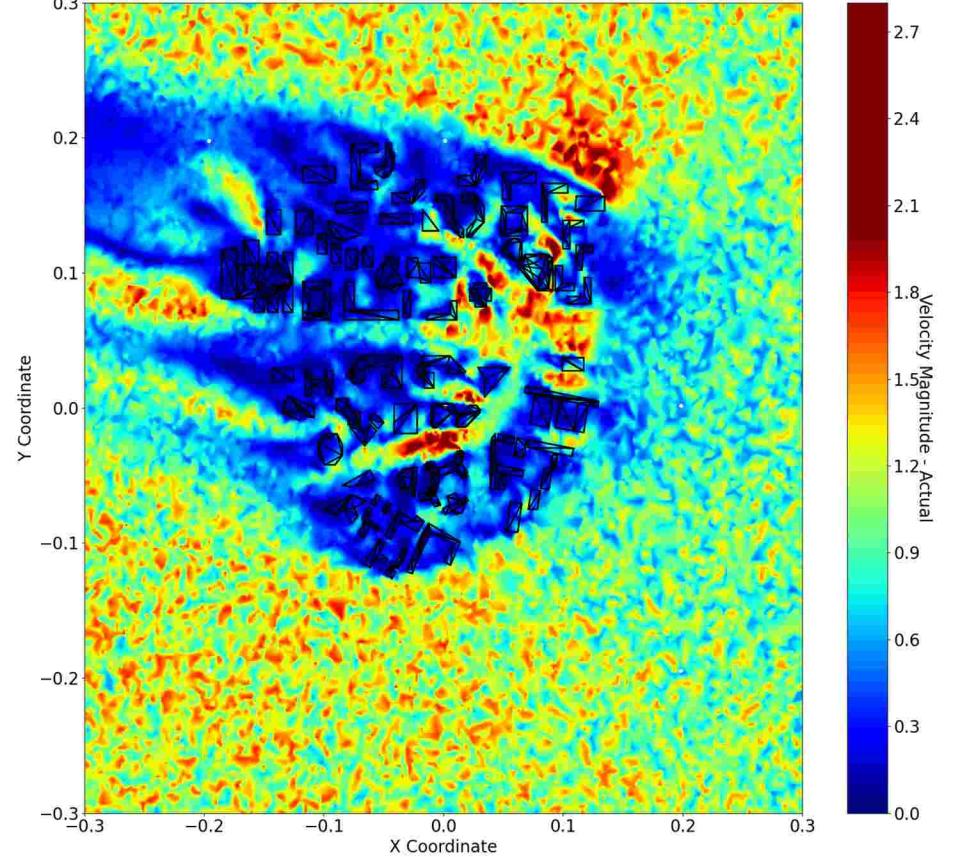


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01
Mean = 1.08 and Standard Deviation = 0.47

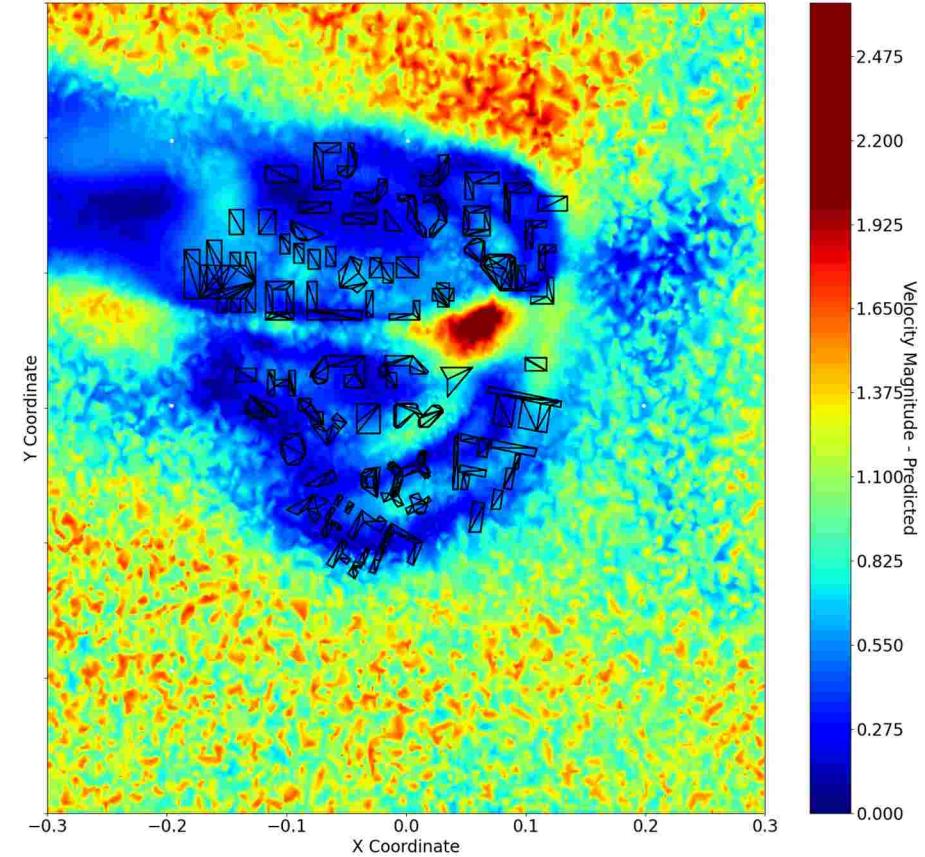


Comparison of Actual vs. Predicted values with Wind Angle = 105 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

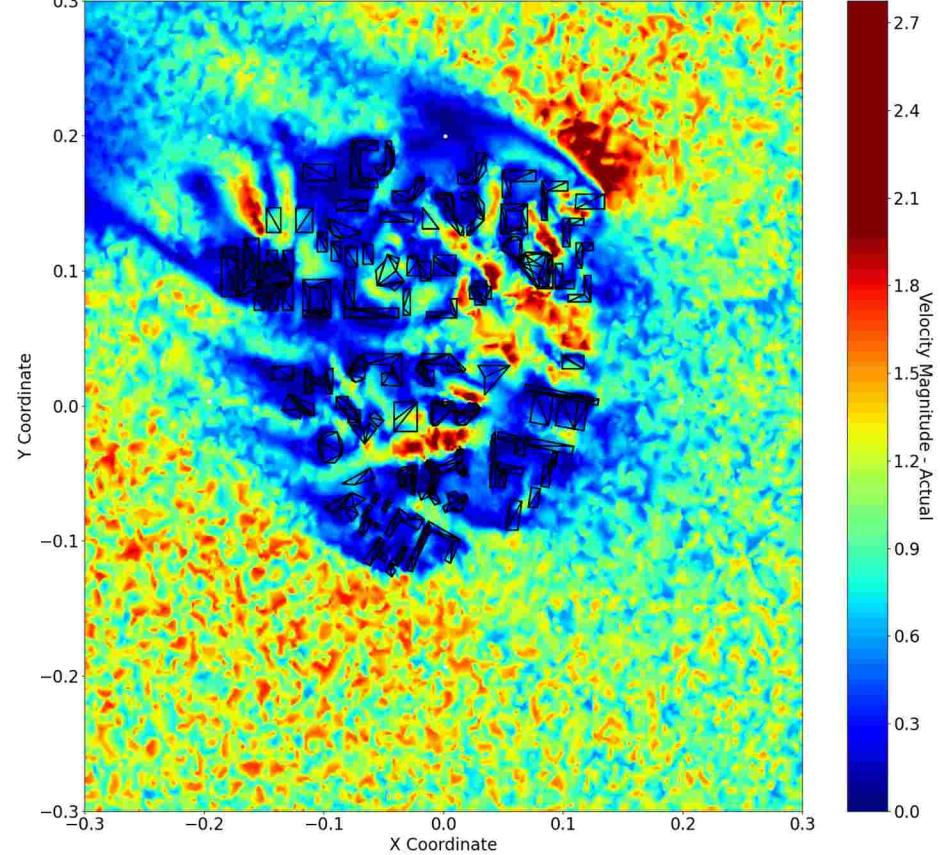


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01
Mean = 1.06 and Standard Deviation = 0.46

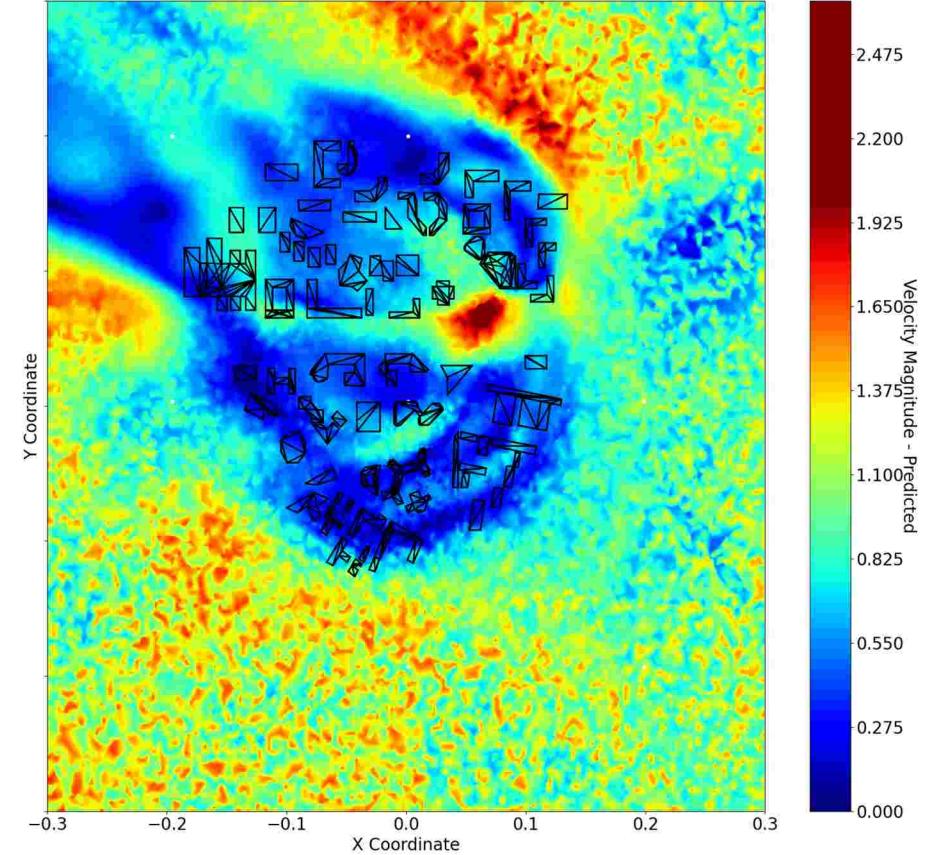


Comparison of Actual vs. Predicted values with Wind Angle = 120 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

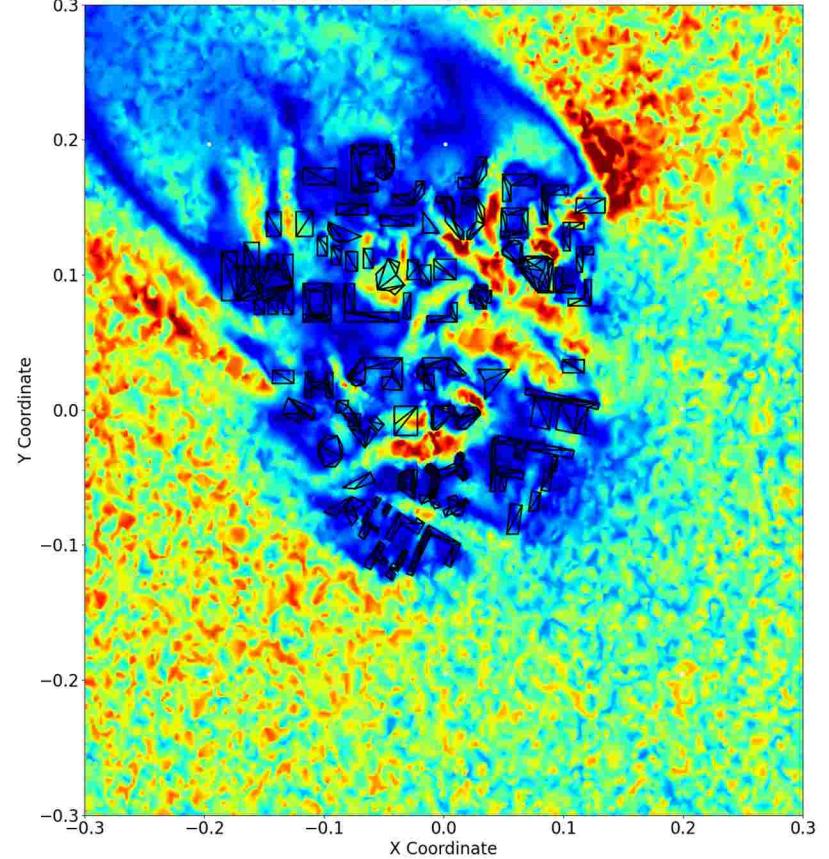


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01
Mean = 1.06 and Standard Deviation = 0.44

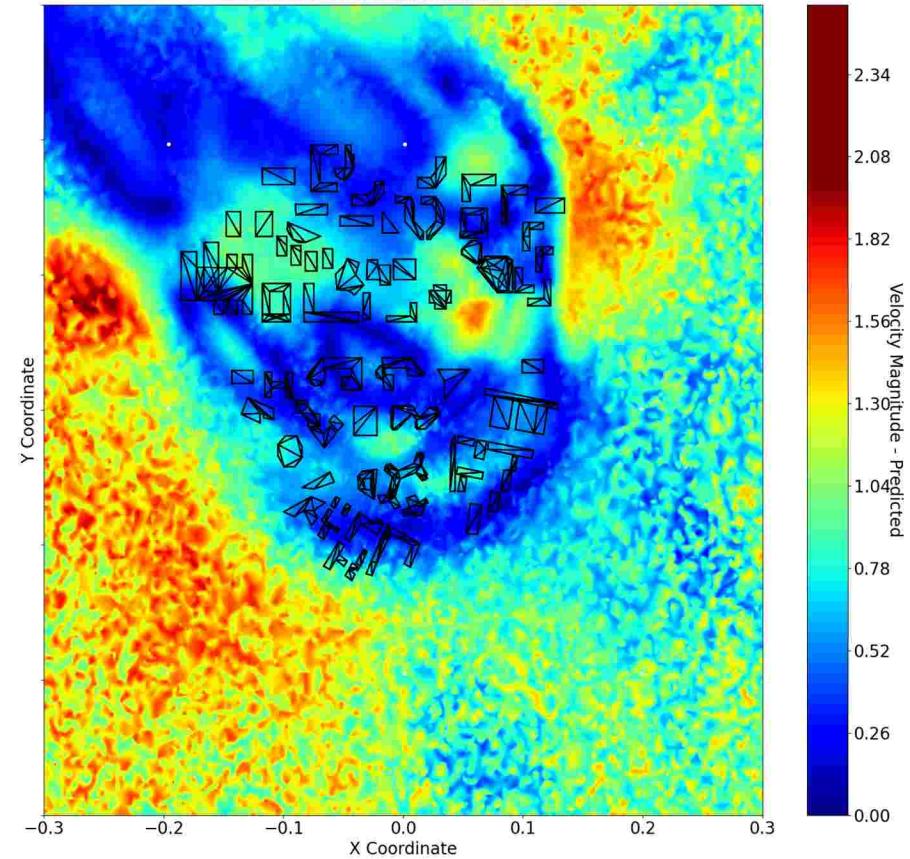


Comparison of Actual vs. Predicted values with Wind Angle = 150 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.50

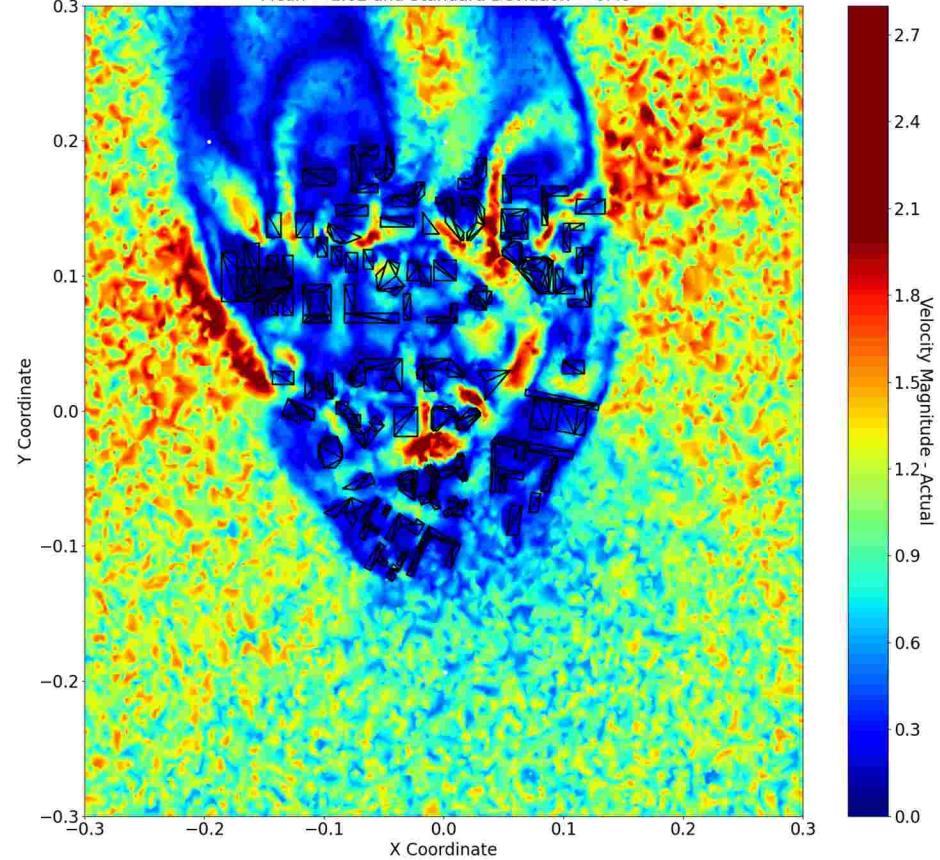


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01
Mean = 0.99 and Standard Deviation = 0.44

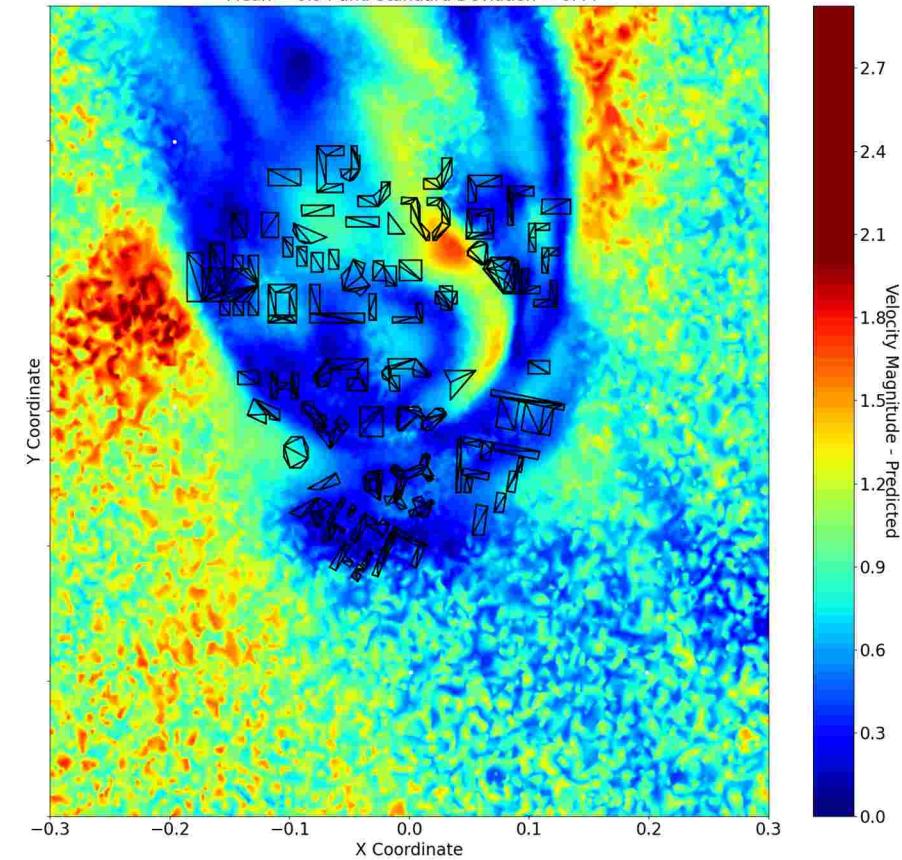


Comparison of Actual vs. Predicted values with Wind Angle = 165 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01
Mean = 1.02 and Standard Deviation = 0.49

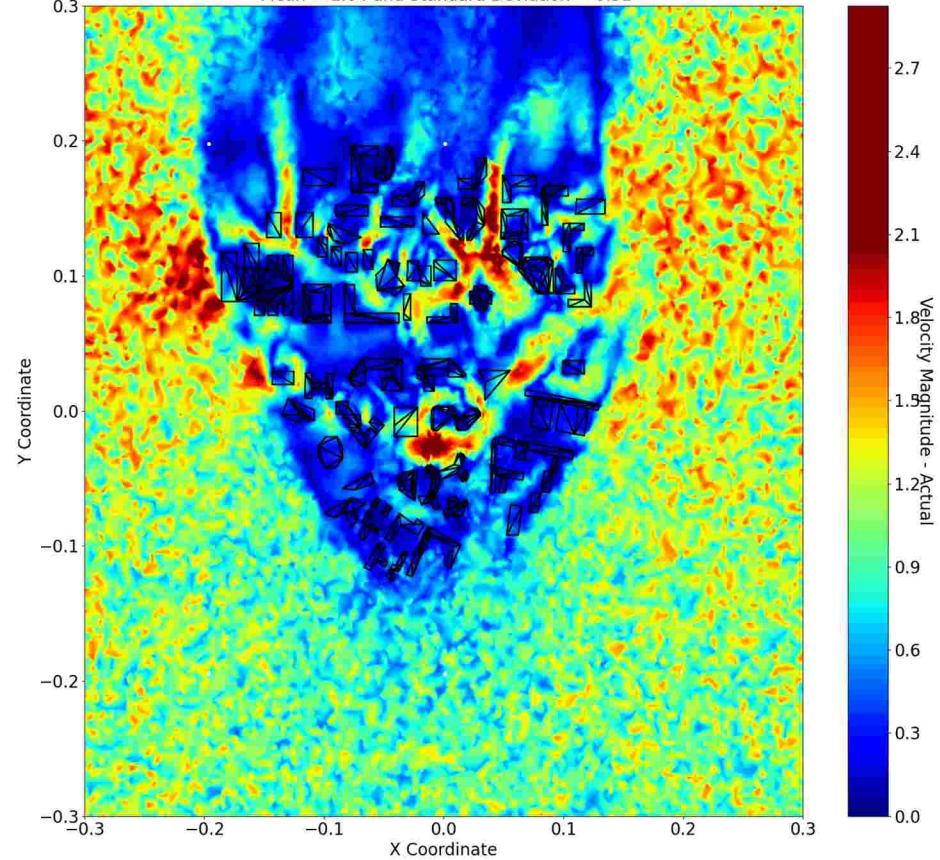


Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01
Mean = 0.94 and Standard Deviation = 0.44

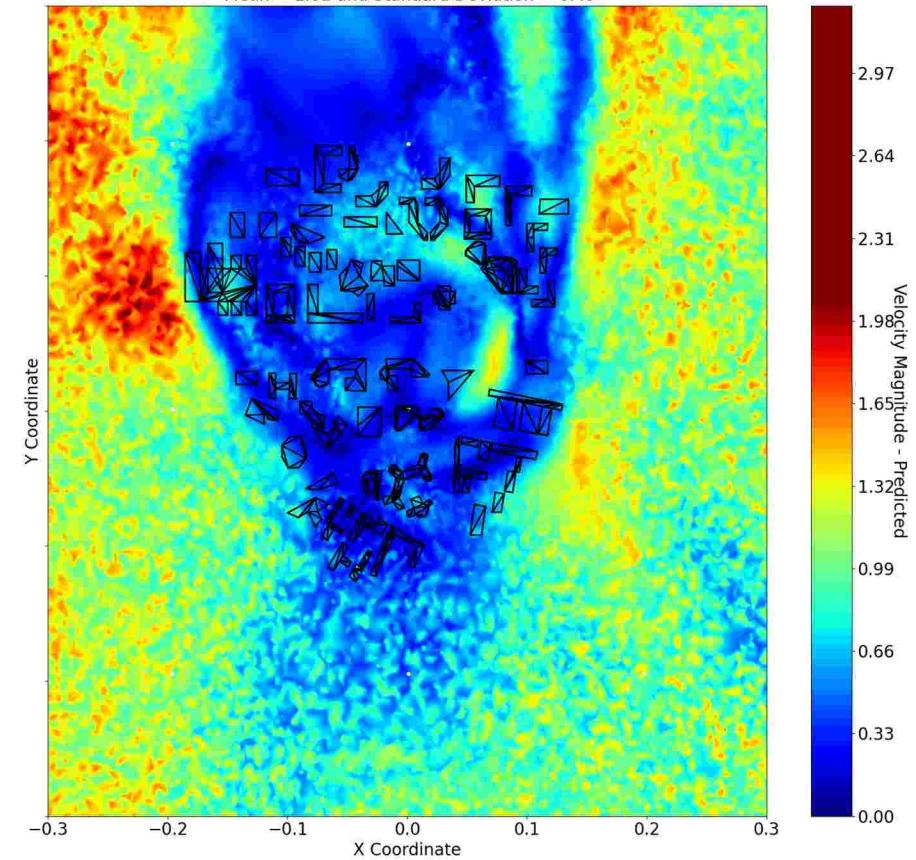


Comparison of Actual vs. Predicted values with Wind Angle = 180 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

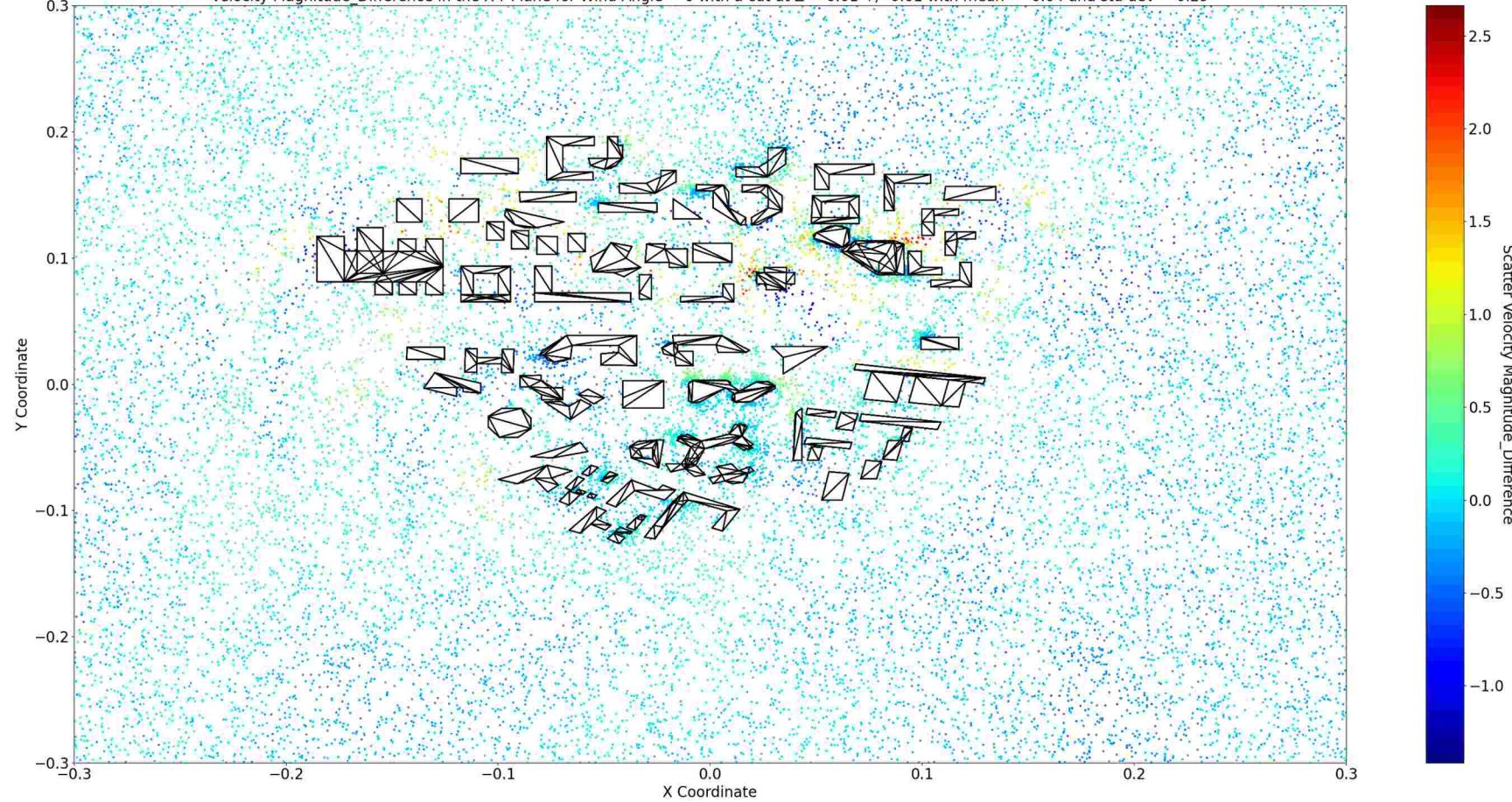
Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01
Mean = 1.04 and Standard Deviation = 0.51



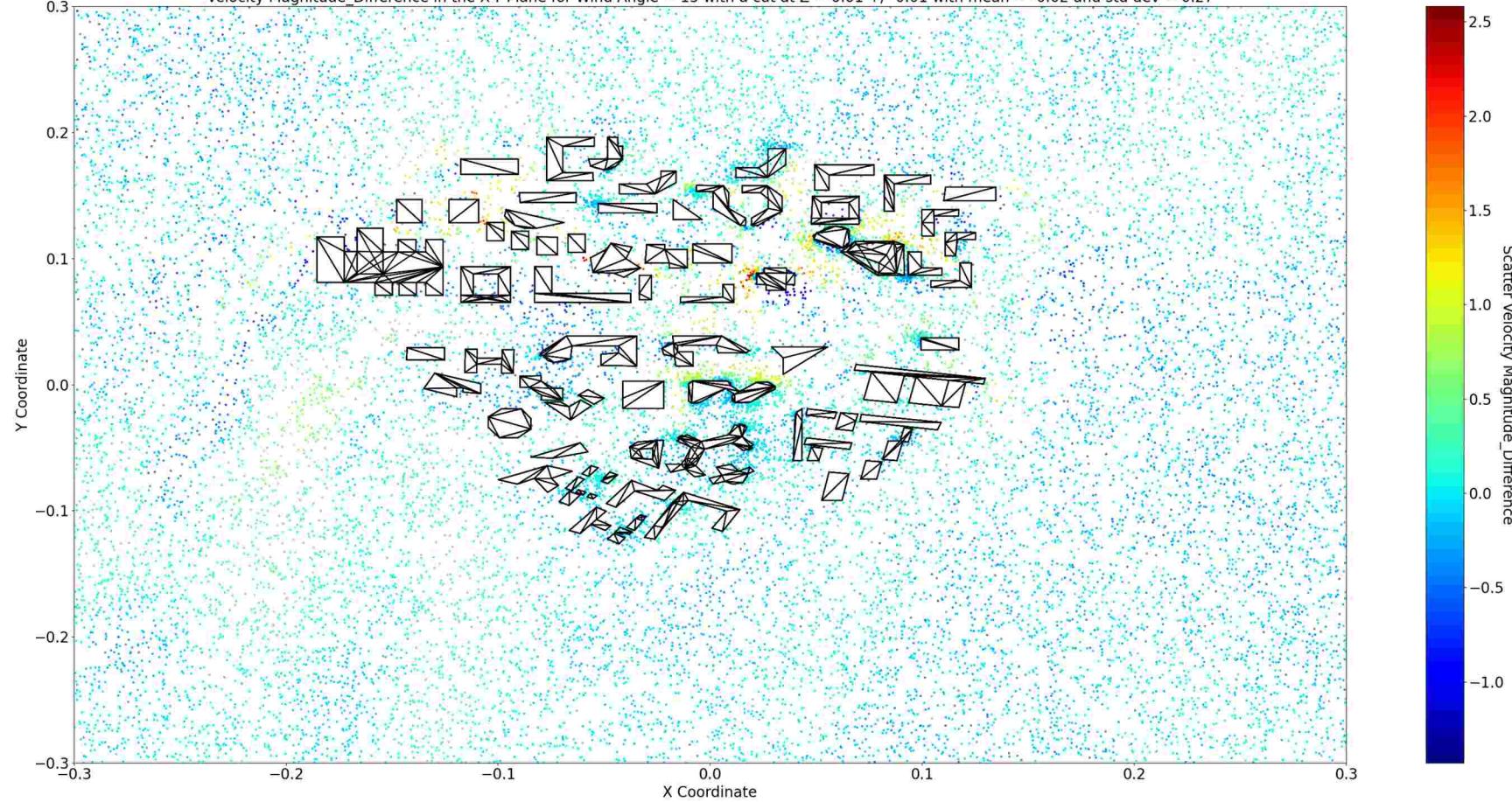
Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.49



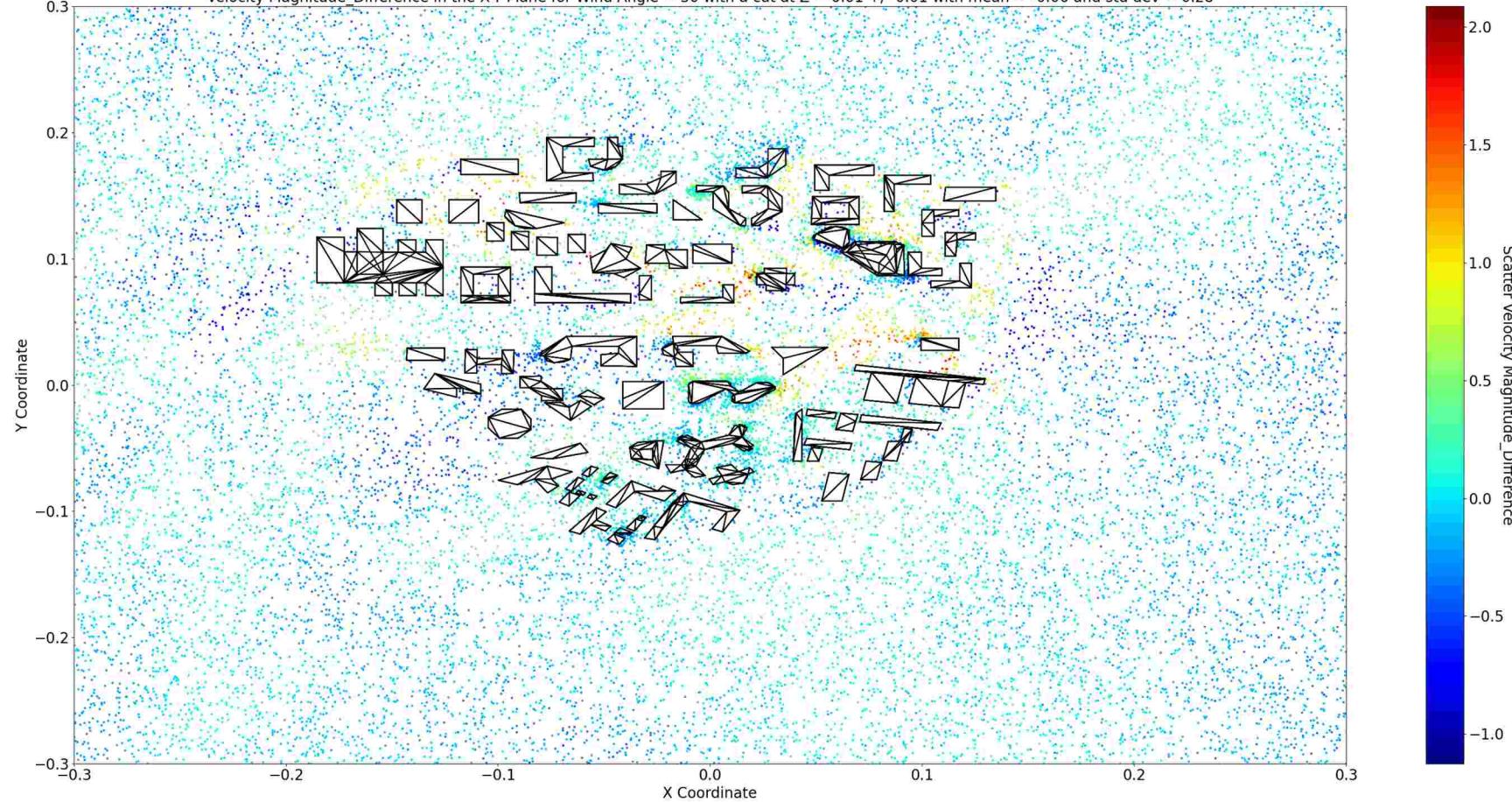
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 0 with a cut at Z = 0.01 +/- 0.01 with mean = -0.04 and std dev = 0.29

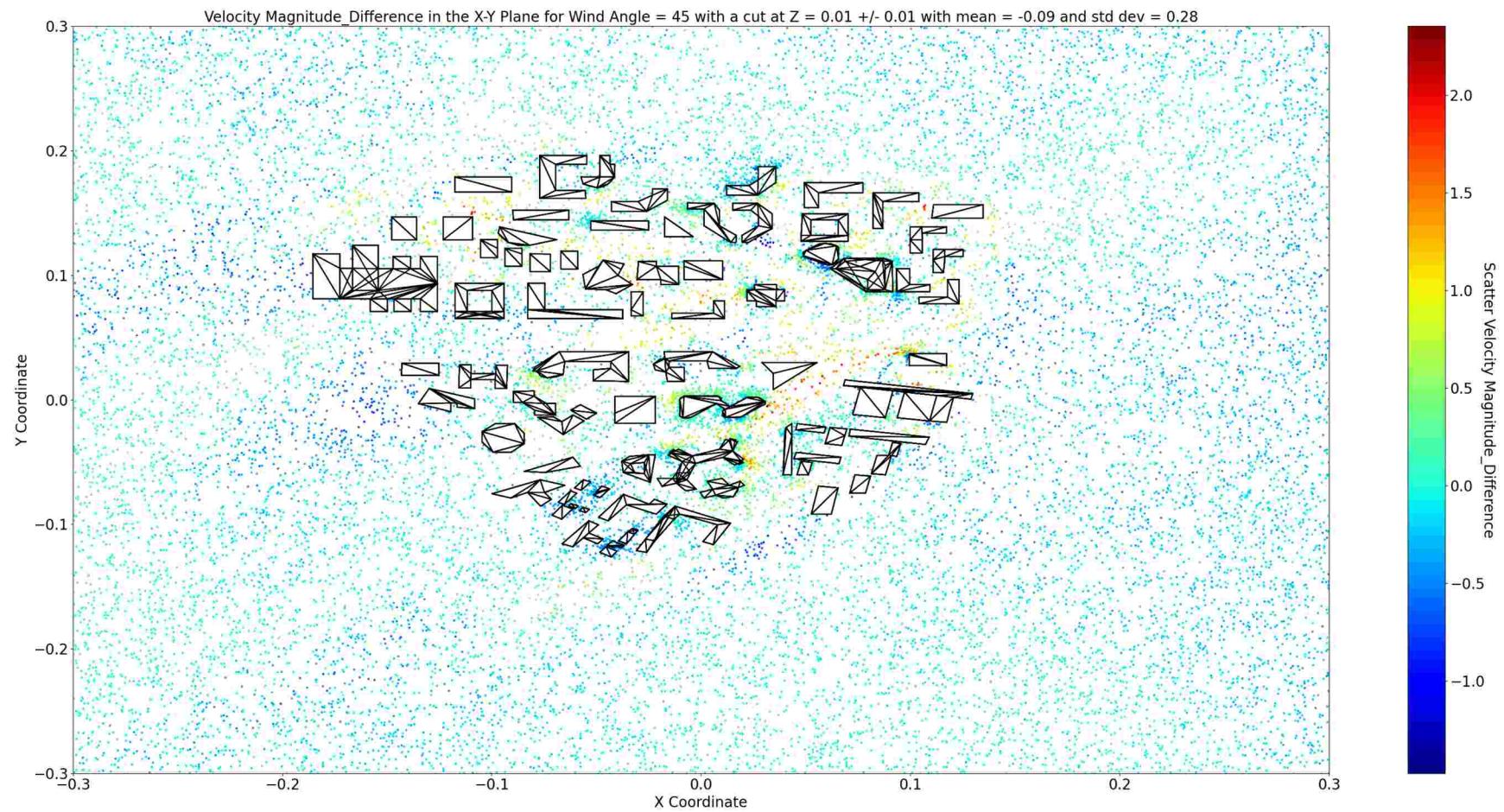


Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 15 with a cut at Z = 0.01 +/- 0.01 with mean = -0.02 and std dev = 0.27

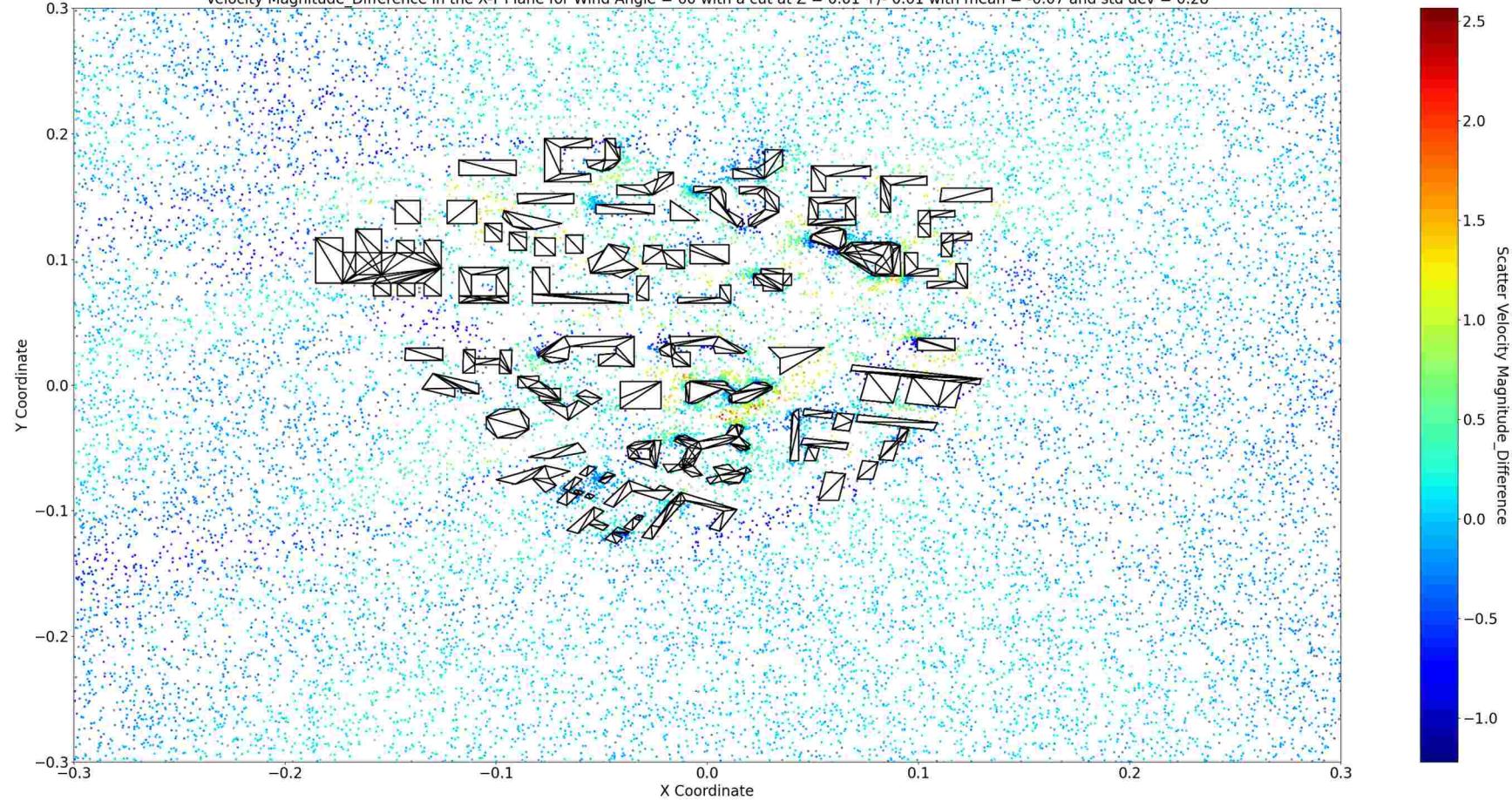


Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 30 with a cut at Z = 0.01 +/- 0.01 with mean = -0.06 and std dev = 0.28

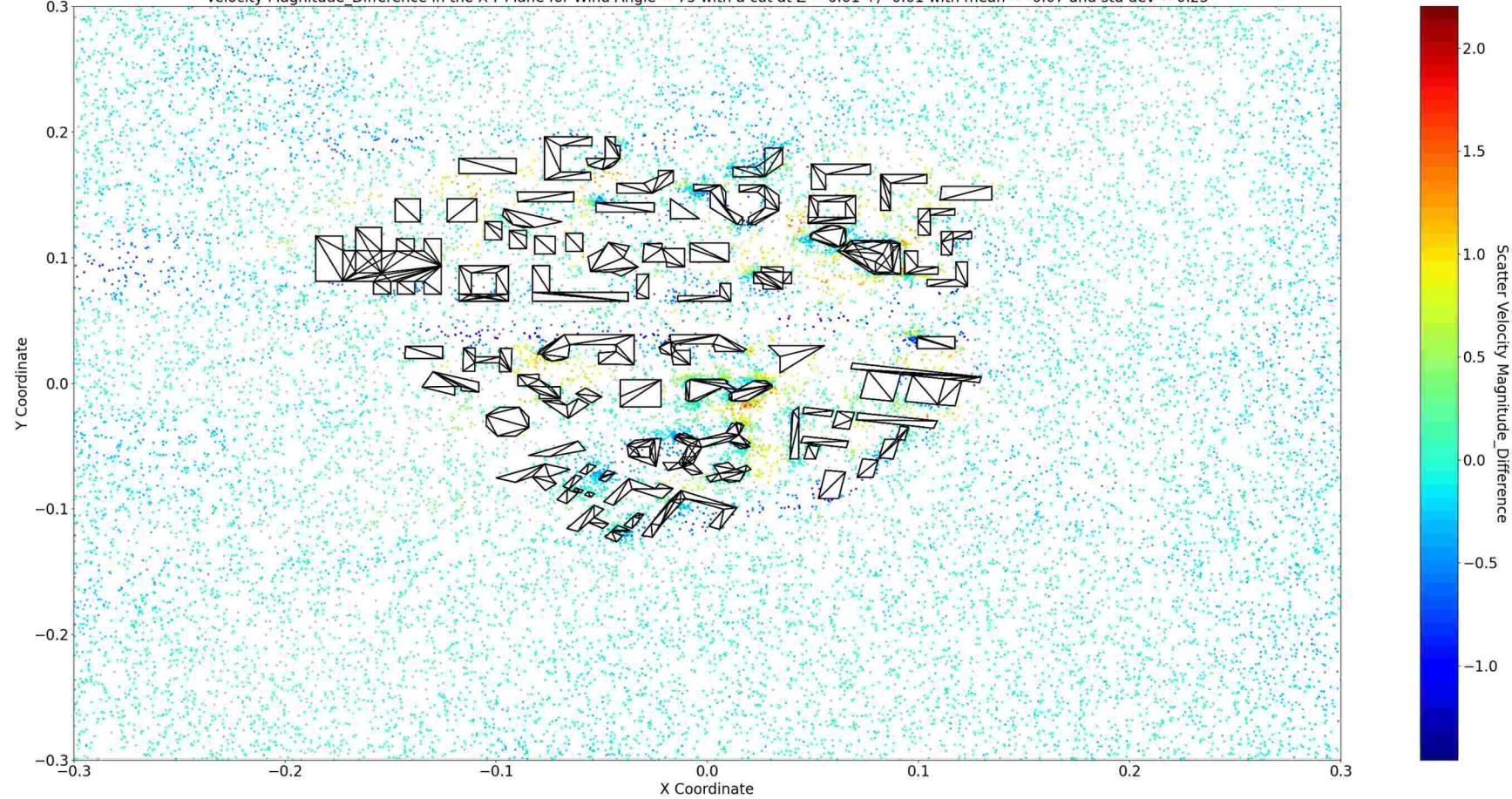




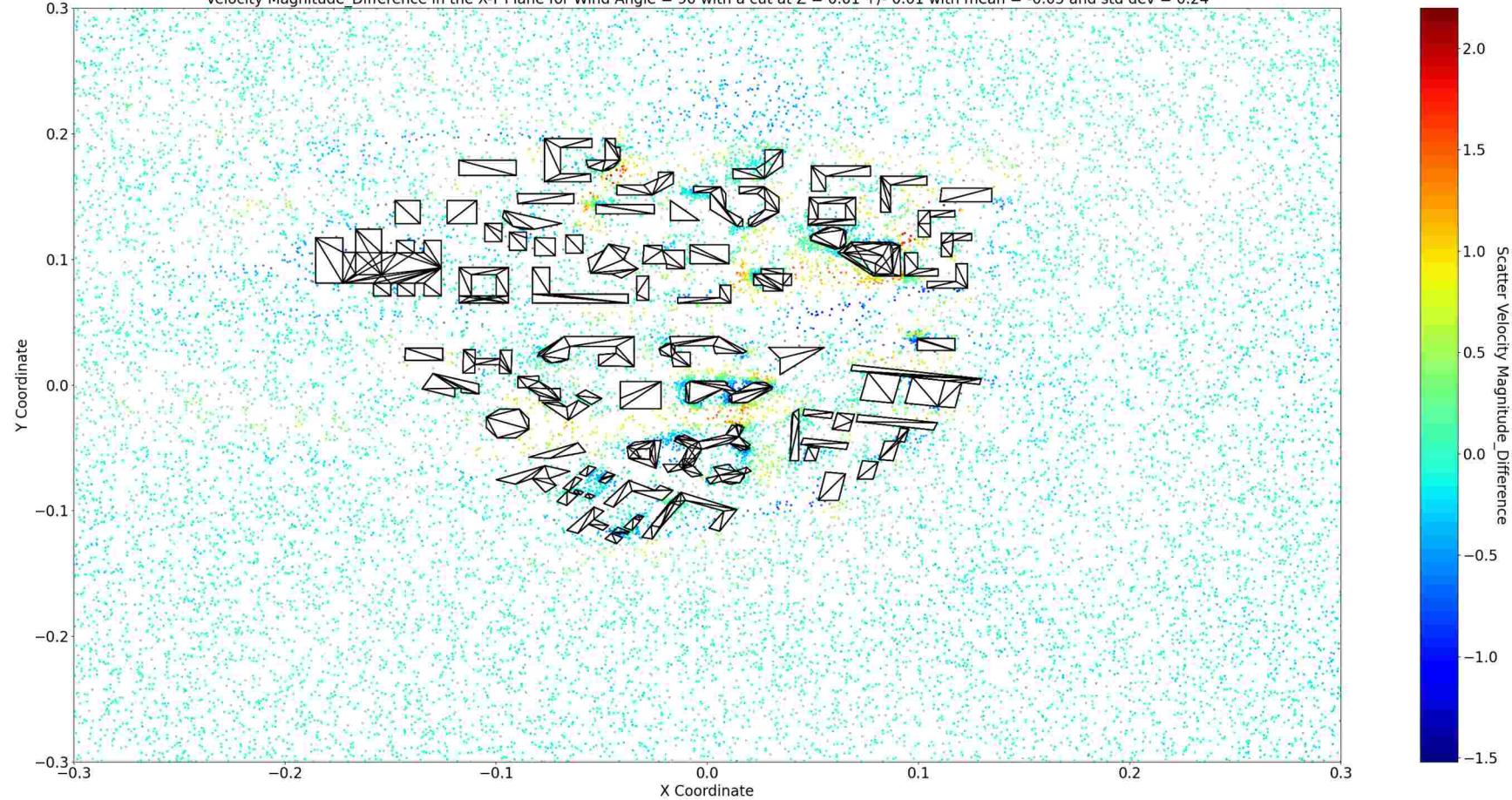
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 60 with a cut at Z = 0.01 +/- 0.01 with mean = -0.07 and std dev = 0.28



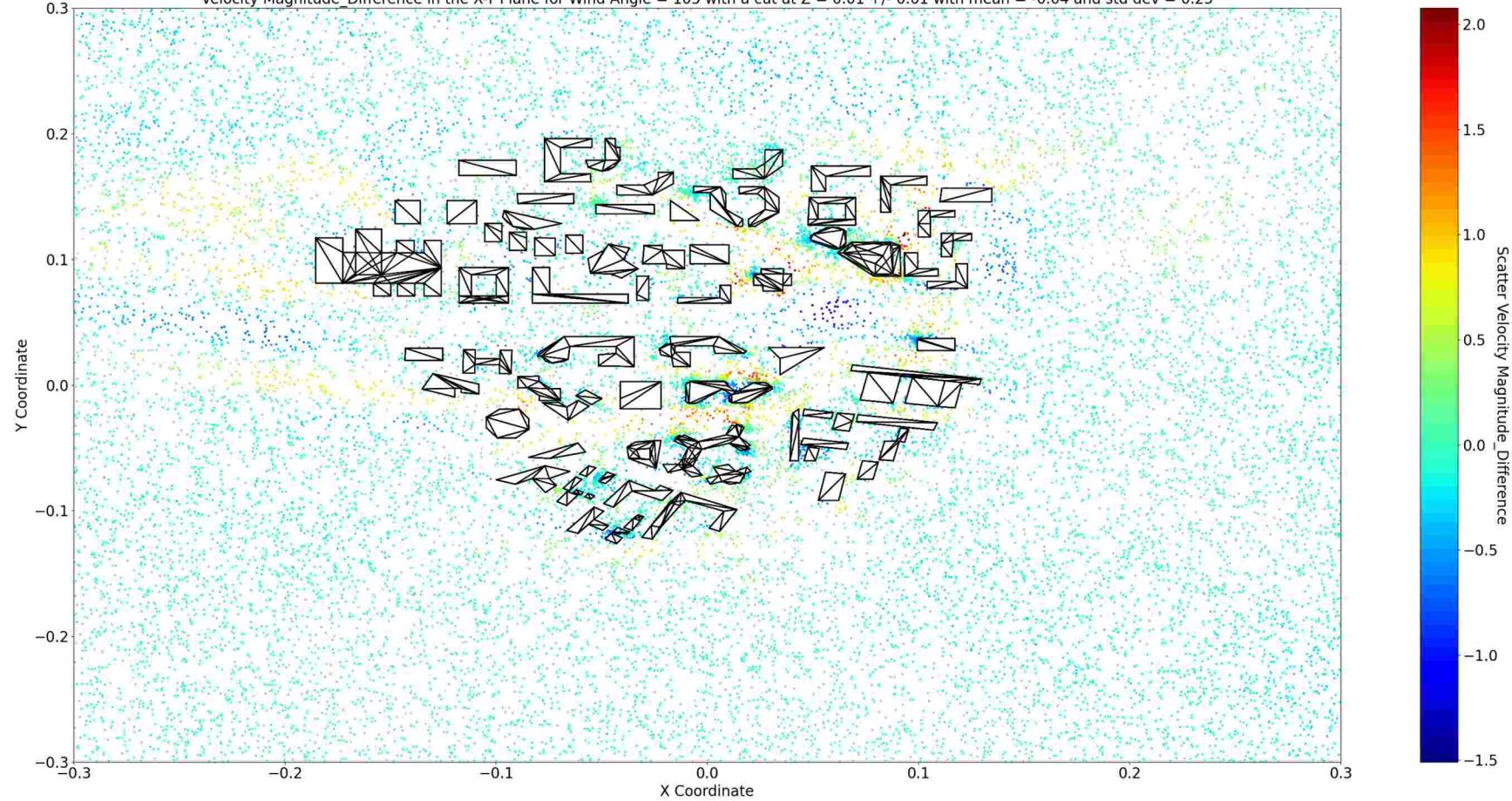
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 75 with a cut at Z = 0.01 +/- 0.01 with mean = -0.07 and std dev = 0.25



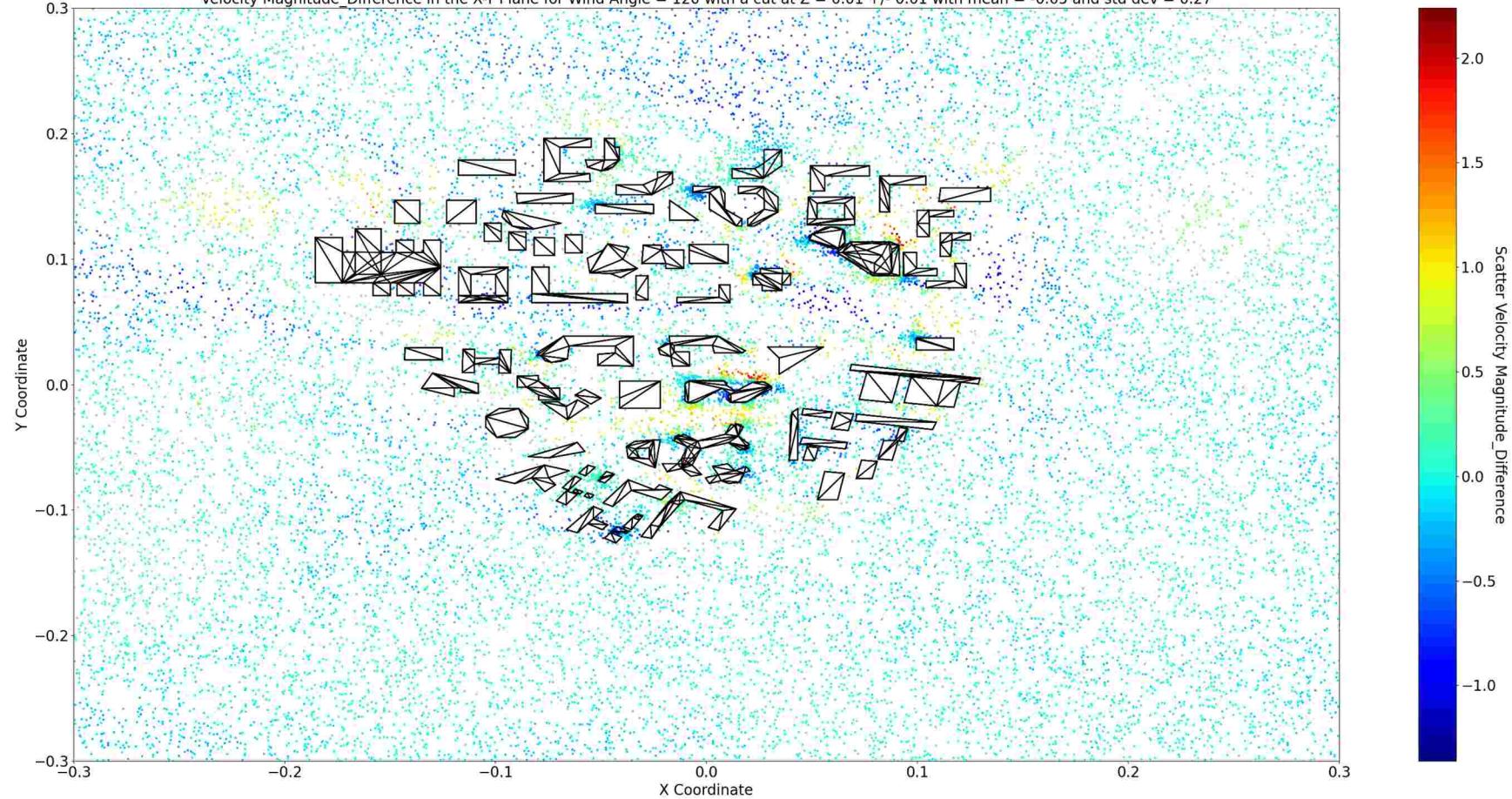
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 90 with a cut at Z = 0.01 +/- 0.01 with mean = -0.05 and std dev = 0.24



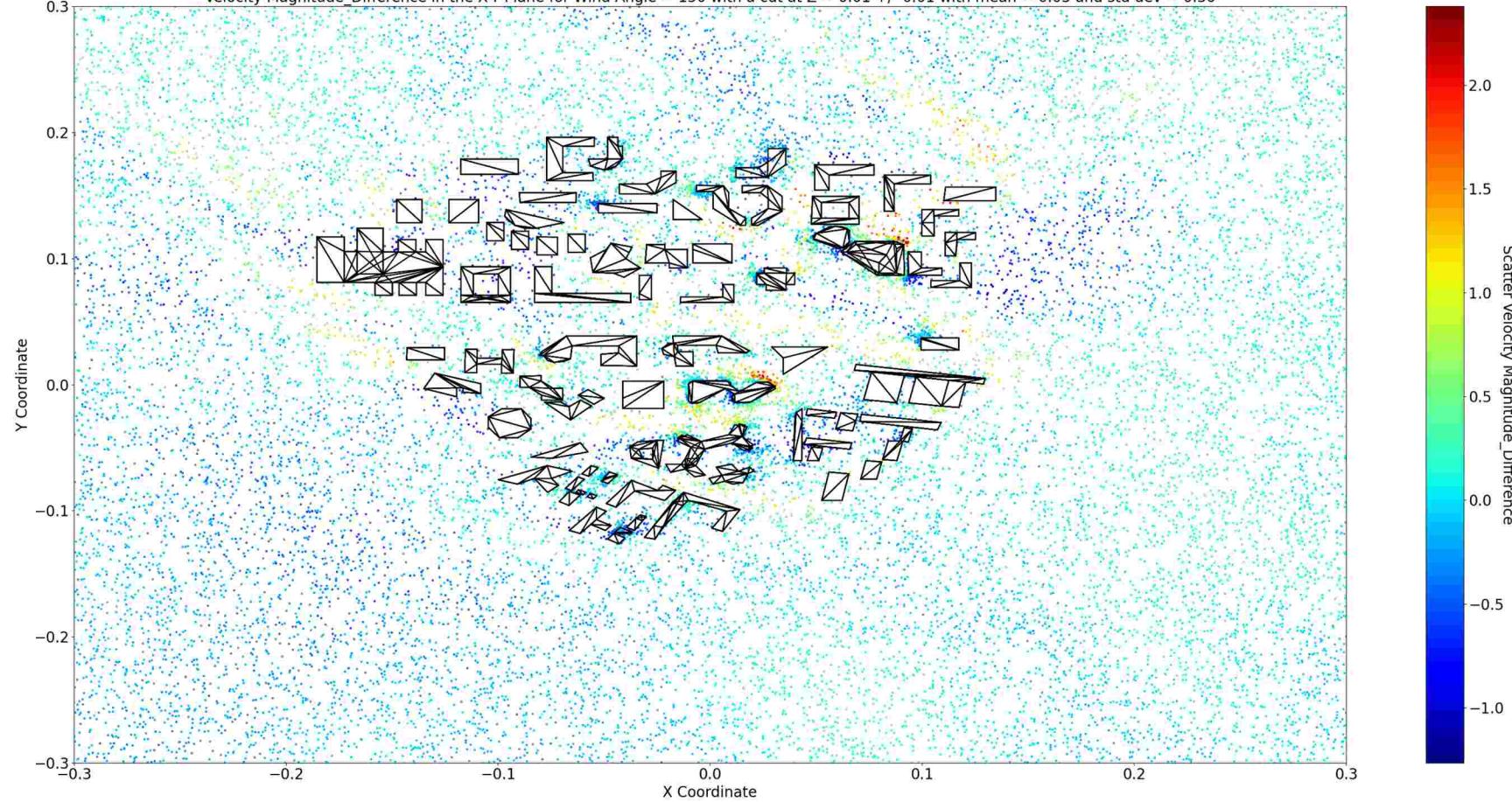
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 105 with a cut at Z = 0.01 +/- 0.01 with mean = -0.04 and std dev = 0.25



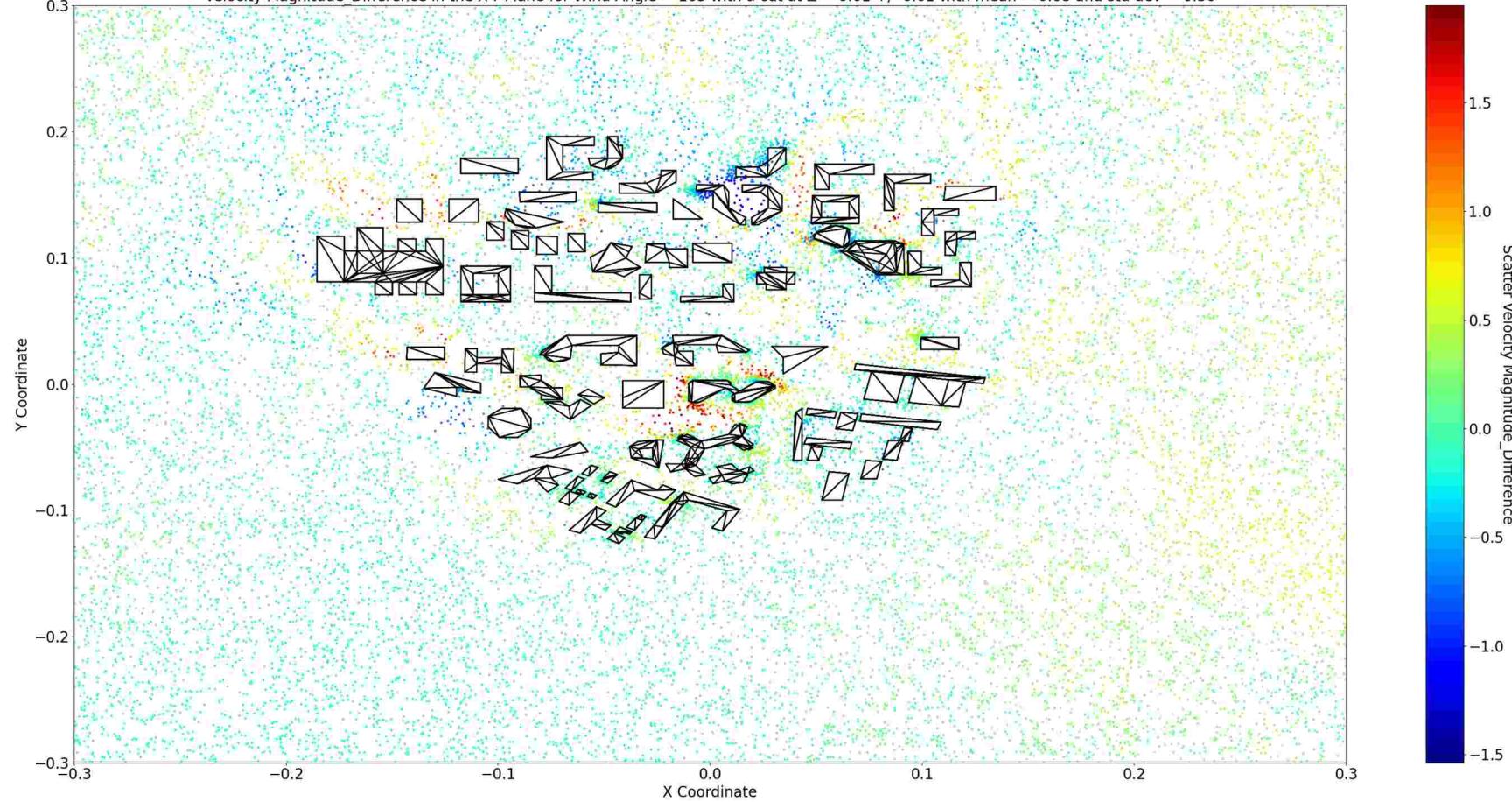
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 120 with a cut at Z = 0.01 +/- 0.01 with mean = -0.05 and std dev = 0.27



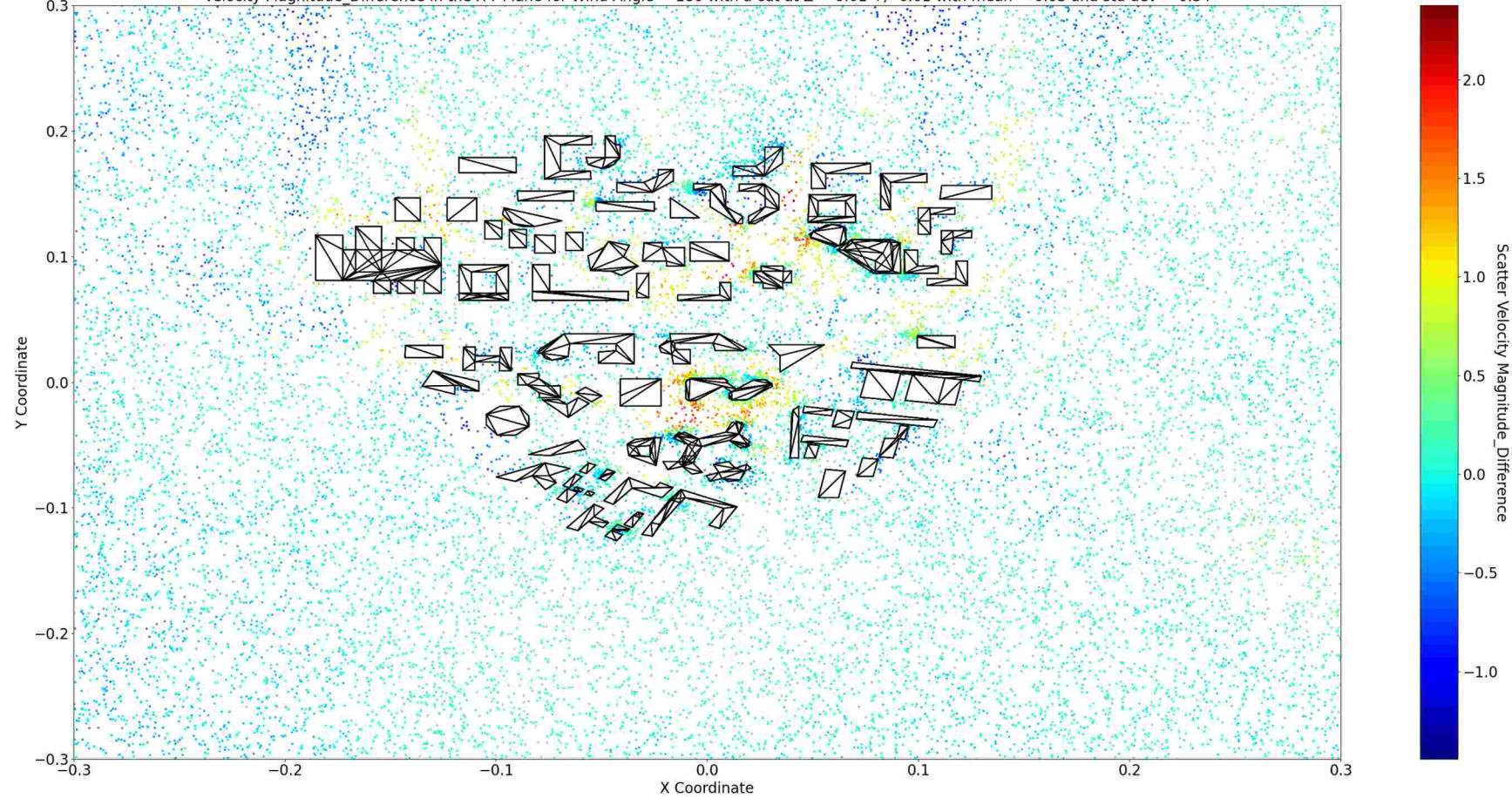
Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 150 with a cut at Z = 0.01 +/- 0.01 with mean = 0.03 and std dev = 0.30



Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 165 with a cut at Z = 0.01 +/- 0.01 with mean = 0.08 and std dev = 0.30



Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 180 with a cut at Z = 0.01 +/- 0.01 with mean = 0.03 and std dev = 0.34



Progress so far - Data Loss Only
Standard Normal Scalar – ELU Activation
(Adam Optimizer)

Threshold = SMA 1E-5 (9 Epochs, not completed), Full Dataset, A100 GPU

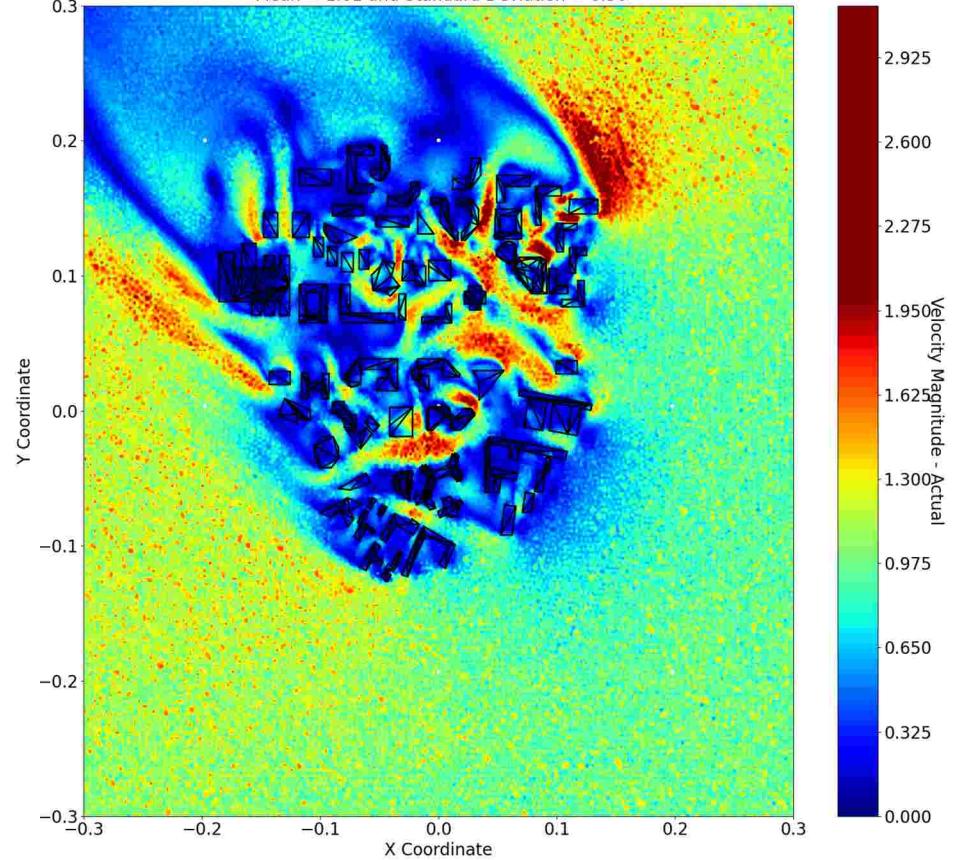
Scripts v5 – PREDICTING

Progress so far - Data Loss Only, Standard Normal Scalar, ELU Activation, Adam Optimizer
Threshold = SMA 1E-5 (121 Epochs, not completed), A100 GPU
Predicting Results – Metrics (Angle = 135)

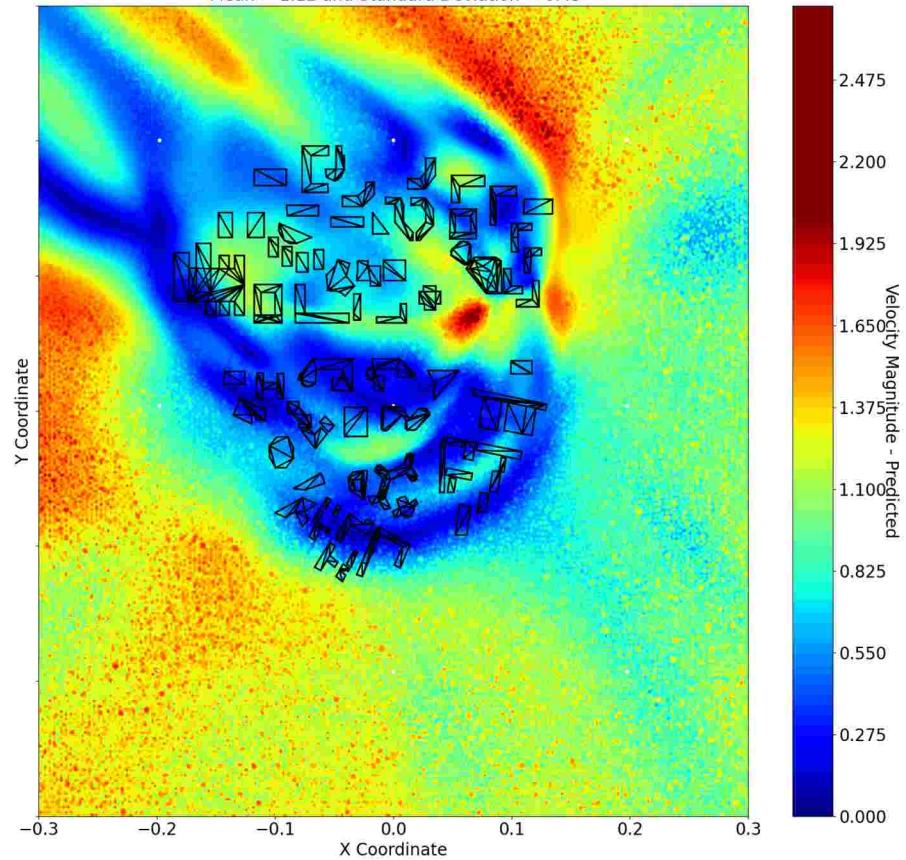
Variable	MSE	RMSE	MAE	R2
Velocity:0	0.21220717	0.4606595	0.4016497	0.80336633
Velocity:1	0.19189125	0.43805393	0.37093559	0.83167827
Velocity:2	0.01057776	0.10284826	0.04309779	0.44504928

Comparison of Actual vs. Predicted values with Wind Angle = 135 in the X-Y Plane with a cut at Z = 0.01 +/- 0.01

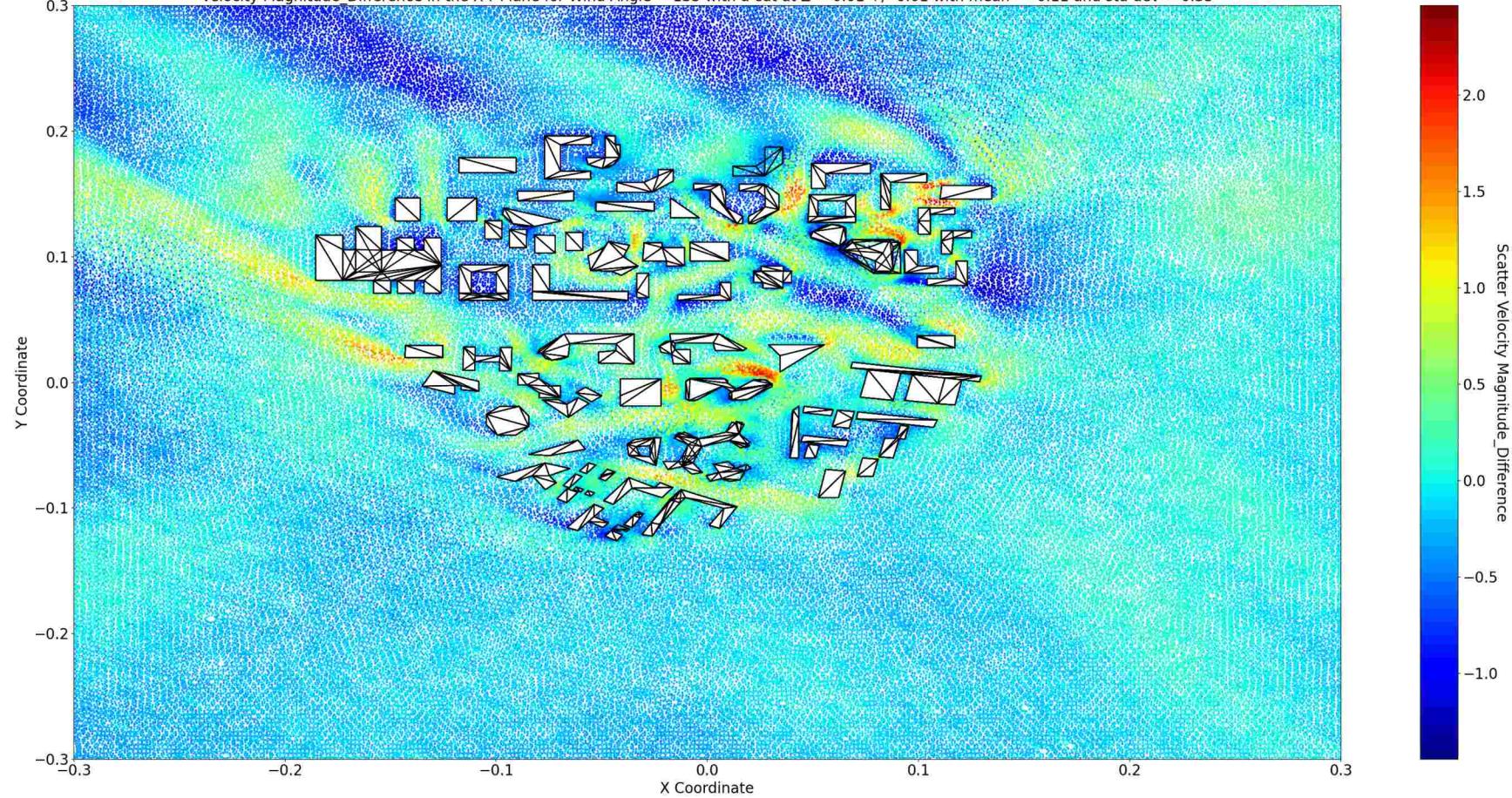
Actual Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01
Mean = 1.01 and Standard Deviation = 0.50



Predicted Velocity Magnitude in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01
Mean = 1.12 and Standard Deviation = 0.45



Velocity Magnitude Difference in the X-Y Plane for Wind Angle = 135 with a cut at Z = 0.01 +/- 0.01 with mean = -0.11 and std dev = 0.33



Discussion

A100 GPU is superior (faster and better learning and predicting) to the GPU Workstation but computationally expensive

500 Compute Units = 75 SGD, 9 Epochs per 500 Compute Units = 1 Epoch Costs 8.33 SGD

Reduced Dataset learns well but prediction is not that good. Data needs to include inlet wind to learn from

Can we make coarser mesh datasets from Paraview? Dataset of Cylinder-Sphere is coarse but good enough for NN to learn from.

Extremely coarse mesh CFD data + physics might work